1.0 Introduction

1.1 Background

Savannas are generally defined as tropical and sub-tropical ecosystems characterized by a continuous cover of C_4 grasses that show clear seasonality related to water and in which woody plants are significant but forming a discontinuous layer (Frost et *al.* 1986). According to Scholes and Walker (1993), savannas are tropical ecosystems in which primary production is contributed both by woody and grass species.

Savannas cover one-fifth of the land surface of the world and approximately half of the African continent (Osborne, 2000). Savannas are mostly distributed in tropical Africa where they cover 65 % of the continent. The savanna areas of Africa (e.g. miombo and mopane woodlands), South America (e.g. campos and llanos) and Australia (e.g. Eucalyptus- Acacia savannas) have a long dry, cool season and a short, hot season (Osborne, 2000).

There are two broad classes of savanna in Africa, the broad leafed and fine leafed savannas. These tend to occur in nutrient-poor high rainfall, and nutrient rich low-rainfall areas, respectively (Gambiza, 2001). The distinction between moist-dystrophic savannas and arid-eutrophic savanns is based on the inverse relationship between soil fertility and rainfall (Huntley, 1982).

Southern African savanna ranges from moist woodlands receiving up to 1800 mm rainfall per year, to sparse grasslands where rainfall maybe as low as 50 mm during drought years. Included in this biome are the miombo and mopane woodlands, grasslands, shrublands and grassy dambos (Huntley, 1982; Burgess *et al.* 2004). Like all types of vegetation, savannas reflect the interplay of environmental conditions in space and time. Their floral composition is in part a legacy of the past, and their present distribution, while closely related to current climatic and edaphic conditions, has been influenced by the long term geological evolution of the landscape as well as the short term effects of herbivory, fire and human cultural practices (Huntley, 1982).

One of the most important savanna vegetation types south of the Equator is the miombo woodland (Campbell *et al.* 1996). This type of vegetation occurs on the central African plateau and sub-tropical climate. In central and southern Africa, miombo ecosystems directly support the livelihoods of some 40 million people. A further 15 million people living in towns and cities depend on food, fiber, fuelwood and charcoal produced under miombo (Campbell *et al.* 1996).

1.2 Justification

Understanding vegetation-environmental relationships at one point may help to predict possible shifts attributed to climate and landuse changes. The correlation between vegetation and environmental variables is one of the most fundamental questions contributing to the understanding of plant species composition and structure in a particular habitat, landscape and region (Mucina, 1997). Although the plant communities are dynamic entities undergoing continuous change in response to climate, landuse patterns and intrinsic dynamics, basic inventories provide a baseline against which changes can be determined (Burke, 2001).

The study area, Mazowe Botanical Reserve, is a high priority biodiversity conservation area and is a designated protected area (Burgess *et al.* 2004). The current political and economic situation in Zimbabwe poses a threat to the extensive system of protected areas. Land invasions threaten protected areas like Mazowe Botanical Gardens (Burgess *et al.* 2004).

Some work has already been carried out on the influence of catenal position on woody vegetation structure and species composition (Mujawo, 2002). No detailed study of the vegetation-environmental relationships has, however, ever been carried out in order to provide a plant-ecological interpretation of the established communities in Mazowe Botanical Reserve.

Information from this study could be useful for proper monitoring, management and conservation of biodiversity in Zimbabwe, particularly in the Mazowe Botanical Reserve. It is hoped that knowledge gained from this investigation would contribute to a better understanding of vegetation-environmental relations in savanna ecosystems of Zimbabwe.

1.3 Aim

The primary aim of this study is to investigate the relationships among physiographic, edaphic, and anthropogenic factors and vegetation structure, species composition and diversity.

1.4 Objectives

The specific objectives of the study are as follows:

a) to investigate the relationship between physiographic factors (i.e. aspect and slope) and, vegetation structure, species diversity and composition in the Mazowe Botanical Reserve;
b) to determine the relationship between edaphic factors and vegetation structure, species diversity and composition in the Mazowe Botanical Reserve;
c) to investigate the relationship between anthropogenic factors (fire and woodcutting) and vegetation structure, species composition and species diversity in the Mazowe Botanical Reserve;
d) to identify the key environmental variables influencing vegetation structure, species composition and species diversity in the Mazowe Botanical Reserve.

1.5 Research Questions

a) How do species composition, vegetation structure and species diversity vary along physiographic gradients?

b) What is the relationship between edaphic factors, and vegetation structure, composition and species diversity in the Mazowe Botanical Reserve?

c) In what ways have anthropogenic factors influenced vegetation structure, composition and species diversity in the Mazowe Botanical Reserve?

d) What are the relative contributions of physiographic factors, edaphic and anthropogenic factors to vegetation structure, composition and species diversity in the Mazowe Botanical Reserve?

1.6 Hypotheses

a) Physiographic factors do not influence vegetation structure species composition and species diversity in Mazowe Botanical Reserve

b) Edaphic factors have no influence on vegetation structure species composition and species diversity in Mazowe Botanical Reserve

c) Anthropogenic factors have no influence on vegetation structure species composition, and species diversity in Mazowe Botanical Reserve

2.0 Literature Review

2.1 Savanna vegetation determinants

Plant-available moisture, available nutrients, fire, herbivory, and human activity are major factors that explain some of the common features and differences in savanna structure and function (Cilliers, 1999; Scholes, 1991; Scholes and Walker, 1993). These factors interact at all ecological scales from landscapes to local patches, but their relative importance differs with scale (Scholes, 1991; Solbrig, 1993). Plant-available moisture and available nutrients are primary determinants of savanna structure and function at higher scales. At a local scale, the patchy distribution of the soil types and topographic features modify plant-available moisture and available nutrients, and together with fire and herbivory, determine the density of the tree layer, the productivity of the system and the rates of nutrient and water flow in the system (Gambiza, 2001).

2.2 Physiographic factors

Physiography is defined as surface features, their form and substance, in a given region or local area (Barnes *et al.* 1998*)*. It is a major ecosystem component, characterized by many different factors, which not only give spatial form and structure to a landscape and its constituent ecosystems, but also significantly affect ecosystem function. The specific physiographic features themselves, the landforms (e.g. slopes, hills and plains) are distinguished not only by their form, but the parent material that is characteristic of a given landform and in which characteristic soils develop. Physiography is important because it is the most stable component, which is least affected by short and long term natural and human disturbances (Barnes *et al.* 1998). The slope gradient or the angle of repose of geologic material is usually measured in degrees.

The orientation of the slope with regard to the sun's position, that is its aspect, is of great importance. At any given latitude, the hottest and driest sites are those that most nearly face the sun during the middle of the summer day. The amount of insolation received on a site influences other related factors including air, soil temperature, precipitation and soil moisture (Barnes *et al.* 1998).

Siebert *et al. (*2002) observed that *Combretum hereroense-Grewia vernicosa* open mountain bushveld in Sekhukhuneland, South Africa, was restricted to cooler slopes of ultramafic valleys, hills and mountains. Surface rocks were predominant and abundant in various habitats. Surface rock cover on slopes varied between 20-70% on the hillslopes, and 10-50% in the valleys. *Enneapogon scoparius-Kirkion- Wilsmii* vegetation association was predominantly found on cool aspects, and occurred on moderate to steep slopes, i.e. 3-15^0. Open mountain bushveld plant associations were found predominantly on southern aspects and those of closed mountain bushveld on northern aspects.

Plant community composition and distribution on isolated mesas (flat-topped mountains) were investigated across Nama Karoo communities in the Eastern Cape, South Africa. Mesa communities were found to be distinctly different from plain communities. The distribution of communities across the landscape was attributed to a soil moisture gradient (Piennar *et al.* 2004). Aspect and the expected more moist conditions on south eastern slopes as factors determining community composition for the dolerite mesas were overridden by soil type and nutrient status. In xeric sandstone mesas such as Buffelskop, soil type and associated nutrient status were overridden by aspect and slope as determinants of community composition (Piennar *et al.* 2004).

2.3 Edaphic factors

2.31 Soil moisture

Soil moisture is a key determinant of savanna structure and functioning (Menaut *et al.* 1995; Skarpe, 1992). It sets a limit on maximum plant productivity and a constraint on types of plants that can survive alternating periods of drought and favourable water relations. Total productivity is also constrained by availability of nutrients. The availability of nutrients is partly dependent on precipitation and past vegetation history and partly on other factors such as parent material (Gambiza, 2001).

Factors influencing the amount of moisture include:

a) quantity and seasonal distribution of annual rainfall;
b) water holding capacity of soil, which is a function of soil texture and depth; and
c) amount of evapotranspiration that is related in complex ways to climate, soil texture, soil surface characteristics and type of vegetation at a site (Frost *et al.* 1986).

Soil texture substantially influences the available soil moisture. The adhesive properties of water, in combination with the large surface area of clay-sized particles, allow clay to hold more water than sand. Silt loam contains the greatest quantities of plant available moisture because of the favourable distributuion of macro and micro pore spaces (Barnes *et al*. 1998).

Grass and sedge species composition were shown to be strongly related to soil moisture regime in the Zambezi valley downstream of Lake Kariba (Dunham, 1989). The first woody plant ordination axis was related to a stand development gradient; *Faidherbia albida* was a pioneer species on lowlying sandbanks and the woody species richness of stands increased with height above the Zambezi River. Two-way indicator species analysis identified 7 vegetation types, which could be separated on the basis of their topsoil texture and flooding frequency (Dunham, 1989).

Kelly and Walker (1975) observed that ecosystem function in the south-eastern lowveld of Rhodesia (Zimbabwe) was to a large extent dependent on soil moisture and consequently on rainfall. Both the total amount of rainfall and its distribution through the season were important in determining plant productivity. Soil moisture and drainage were reported to be influencing community distribution for a mountain catchment study site at Zachariashoek, in the Cape Province. Field observations indicated that relative abundance and distribution of the communities described seemed to be governed by moisture regime in terms of water availability and drainage potential (van Wilgen and Kruger, 1985).

Landscape and climatic influence on woody vegetation in a dry woodland/savanna/shrub-steppe ecosystem was explained by analyzing the abundance and distribution of woody vegetation in relation to landscape and rainfall gradients (Coughenour and Ellis, 1993). Findings suggested that dry tropical ecosystem structure is hierarchically constrained by physical factors: by climate at regional to continental scales; by topographic effects on rainfall and landscape water redistribution, and geomorphic effects on soil and plant moisture available at the landscape to regional scale; and finally water redistribution and disturbance at local and patch scales (Coughenour and Ellis, 1993).

El-ghani (2000) assessed vegetation-environmental relationships in two extreme desert zones of western Egypt. Salinity; fine sediments and moisture content were reported to be the important factors controlling the distribution of accidental vegetation. Soil-texture gradient existed from sandy uplands to fine textured flats in arid desert environments and this resulted in gradients of available moisture. Moisture content was one of the most effective physical factors leading to vegetation variations in the study area (El-ghani, 2000).

In a study of vegetation-environmental relationships in coastal mountains of the fynbos, MacDonald *et al.* (1996) showed that the principal gradient was a precipitation gradient. The response of vegetation was dominated by the change from wet to dry conditions (Macdonald *et al.* 1996). Variation in the mountain habitats to which the vegetation responded could be predicted from a combination of a few environmental variables. The principal gradient was one of change from high to low mean annual precipitation (Macdonald *et al.* 1996).

Shackleton, (1999) studied woody community phenology in the central lowveld, South Africa, over a twelve-month period at three sites along a rainfall gradient, with both top lands and bottomlands sampled at each site. Soil moisture, as determined by rainfall and soil texture, had a marked effect on woody community phenology in savannas. In particular, increasing aridity resulted in the concentrations of growth related phenophases into a shorter period of time, and a greater proportion of stems losing leaves in the dry period (Shackleton, 1999).

Tropical dry forests, woodlands and savannas show natural boundaries, which are largely influenced by water availability in interaction with fire, soil nutrients and herbivores. Available water is only partly a function of climatic factors, mainly rainfall and potential evaporation (Skarpe, 1992). Results of an extensive vegetation survey of 214 miombo woodland sites in the northern region of Zimbabwe were reported. Available soil moisture was observed to be the major factor influencing plant species distribution and composition (Kanschik and Becker, 2001).

2.32 Soil nutrients

Savanna soils vary widely in texture, structure, profile and depth. This reflects the interaction of geology, geomorphology and climate at one scale, and the influence of topography, relic features of past landforms, the kind and extent of vegetation cover, and animal activity at another scale (Frost *et al.* 1986). Physical characteristics and the underlying geologic formation determine both nutrient content and the water nutrient retention capacity of a soil. The availability of nutrients is influenced by parent geology, rate of weathering and transport of materials into and out of an area by water (Bell, 1982).

Soil fertility is inversely related to rainfall. In high rainfall areas, nutrients are lost through leaching. This negative correlation between rainfall and soil nutrient-availability is the basis for the distinction between moist-dystrophic savannas and arid-eutrophic savannas (Huntley, 1982).

Soil depth, pH and position relative to the upper or lower forest fringe were shown to be strongly related to vegetation composition on three inselbergs in continental Equatorial Guinea (Parmentier, 2003). There was no effect of slope or aspect. Though the three inselbergs were very close to each other they significantly differed in their vegetation (Parmentier, 2003)

In Southern African savannas, topo-edaphic conditions are important determinants of vegetation structure and composition at regional or local scale (Coughenour and Ellis, 1993; Witkowski and O'Connor, 1996). Topo-edaphic variables and previous cultivation were the main determinants of floristic variation in Weenen Nature Reserve, KwaZulu-Natal (Breebaart *et al.* 2001). Half the dominant woody species exhibited a reverse-J size class structure, indicating relatively constant populaion change. A number of species had a preponderance of individuals in the smallest (0.5-1.5m height) size class, owing possibly to recruitment and/or the inability of individuals to escape the 'fire trap' (Breebaart *et al.* 2001).

Changes in vegetation structure have been attributed to spatial changes in both nutrient status and levels of concentrations of growth limiting minerals like nitrogen and phosphorus. Woody plant species display a number of physiological respones to gradients of environmental factors, particularly soil physico-chemical condition (Aerts, 2000).

2.4 Anthropogenic factors

Man can affect savanna structure either directly, as woodcutters and cultivators, or indirectly through their ability to manipulate fire and to influence herbivore numbers and distribution. In more recent times man has developed the capacity to bring considerable change in savanna structure and function through mechanical and chemical means. Man's activity may be a major source of disturbance to savanna ecosystems (Frost *et al.* 1986). According to Cilliers (1999) high levels of disturbance and environmental modification due to man's activities have been linked to ever increasing synathropisation of vegetation. Synanthropisation refers to the totality of changes in the plant cover caused directly or indirectly by man's activities (Cilliers, 1999).

Anthropogenic disturbance decreased the dominance of single species in forests of Central Himalaya (Arvind and Jeet, 2005). Plant biodiversity increased due to the mixing species of different successional status. Species richness and diversity for all vegetation layers were higher in low elevation-high disturbance forests. Shrub density decreased from high to low disturbance. The mean number of young individuals increasing from high to disturbance indicated that regeneration was adversely affected by disturbance (Arvind and

Jeet, 2005). Low elevation forests close to human habitation had high disturbance frequency. High elevation forests situated far from human habitation had low disturbance.

2.41 Fire

Fire has a profound effect on savanna structure and growth of vegetation (Bond and van Wilgen, 1996). Fires reduce standing biomass and litter, and may kill individual organisms, seeds, seedlings and unprotected plant tissues. Fire also changes the energy, nutrient and water fluxes between the soil and atmosphere. The nutrient status and productivity of savannas are determined in part by the frequency, timing and intensity of burning (Gambiza, 2001).

The fire regime of an ecosystem has four components:

i) frequency, the reciprocal of the mean time between fires

ii) intensity, the rate of energy release i.e. hotness

iii) season of burning; and

iv) type of fire, with or against the wind, on the ground or in the tree canopy (Scholes and Walker, 1993; Gambiza *et al.* 2000).

Fire is an important component of savanna ecosystems. Heat may enhance germination of burned seeds (Bond and van Wilgen, 1996), but it may also kill seeds (buried or not) and young seedlings. Fire can also act indirectly on plant recruitment, growth and survival by diminishing above ground biomass. Competition is reduced and light penetration to the soil surface increases (Frost and Robertson, 1985), and this affects community structure and species diversity.

Garnier and Dajoz (2001) investigated the effects of fire on the demography of population of a long-lived perennial tussock grass, *Hyparrhenia diplandra* in a West African savanna that burns annually. Seedling growth, survival and fecundity were recorded in burned and unburned plots. The asymptotic population growth rate was higher in the unburned model (λ=1.23) than in the burned model (λ=1.07), indicating that the population of *H. diplandra* expanded quickly in the absence of fire. Overall, results indicated that annual burning limits population growth rate. Less frequent but still regular fires allowed establishment while preventing the accumulation of litter and accelerating nutrient cycling, leading to more stable populations in the absence of fire (Garnier and Dajoz, 2001).

There is great variation in seedling survivorship among miombo trees. In some species, seedling mortality is caused by drought, herbivory and fire. Fire causes high seedling mortality in *B. spiciformis,* but has little effect on *J. globiflora* seedlings (Chidumayo, 1993). In a factorial experiment designed to evaluate the effects of cover and prescribed burning on seedling establishment, greater seedling establishment occurred under the crowns of trees than in open grasslands. Burning had an overall negative effect on seedling establishment in the first year following burning, and by the second year, establishment had returned to control levels (Hoffman, 1996).

The role of fire in determining biome distribution in South Africa has long been debated. Bond *et al.* (2003) tested the relative importance of fire and climate in determining ecosystem characteristics by simulating potential vegetation of South Africa with and without fire using a Dynamic Vegetation Model (DGVM). Collated results of long-term fire exclusion studies to test the relative importance of fire and climate showed that grassy ecosystems with rainfall >650 mm tend towards fire-sensitive forests. Areas below 650 mm showed changes in tree density and size but no trend of changing composition to forest (Bond *et al.* 2003).

Not all woody species are equally sensitive to fire. The fire tolerance of 21 woody species in dry miombo woodland in the Central Province of Zambia was evaluated. *Brachystegia spiciformis* and *Julbernadia globiflora* were classfied as fire-sensitive (Cauldwell and Zieger, 2000). *Dichrostachys cinera* was recorded to have 100% mortality rate in dry miombo woodlands after repeated exposure to fire (Chidumayo, 1994). According to the results of the study, only *J. globiflora* was fire-sensitive whilst *Burkea africana, Monotes,* and *Pseudolachnostylis maprouneifolia* were fire-tolerant or semi fire-tolerant. Repeated exposure to fire can convert miombo woodland to open woodland of fire tolerant species (Cauldwell and Zieger, 2000).

Man-made dry season fires have been reported to cause considerable stem mortality, especially in regrowth areas. Chidumayo (1988) gave stem mortality of 4 % and 40 % under early and late dry season burning, respectively. Fire not only retards miombo regrowth, but also thins out stem density (Chidumayo, 1993). In the absence of fire, interstem (among multi-stemmed coppiced plants) and interplant competition ultimately regulates both stem and plant diversity in regrowth miombo (Chidumayo, 1993).

Regeneration mechanisms of vegetation and the role of tree bark resistance to frequent fire was studied in savanna woodlands and grasslands in Gambella, Western Ethiopia. The variation between sites in species composition and biomass correlated with the differences in fire intensity. Both facultative and obligate sprouters significantly contributed to post fire recovery (Gashaw *et al.* 2002). Adaptations to fire in tree species seemed to include the development of a thick bark, once the tree has passed seedling stages. Tree bark thickness and tree diameter at breast height were strongly correlated with the time taken for cambium to reach an assumed lethal temperature of 60 ^{0}C when exposed to fire (Gashaw *et al.* 2002). This indicated that mature trees with thick barks might resist stronger fire better than, e.g. small or young trees and trees with thin bark.

Variability of vegetation response to single fire- events was explained along a productivity gradient and was also found to be habitat dependent in the Okavango Delta (Heinl *et al.* 2004). Floodplains showed a decrease in biomass after the fire event. Mopane woodlands showed an increase of standing biomass after the fire event. No specific plant trait was favoured by the fire event and only *Urochloa mozambicencis* showed a highly significant correlation to burning. Major changes were observed in vegetation structure, e.g. height and cover of the herb layer or biomass production (Heinl *et al.* 2004).

Chidumayo (1988) reported changes in species composition and diversity in woodland either burnt or protected from fire over long periods. Directions of change were related to age and regenerative phase of the woodland. Increase in fire frequency resulted in reduced tree species composition. Low species richness in regrowth miombo has been attributed to fire (Chidumayo, 2004).

Fire often interacts with other environmental factors to influence vegetation structure and composition. In a study of miombo woodlands in Sengwa, Zimbabwe, direct and indirect gradient analysis showed that edaphic and disturbance factors had significant influence on species composition (Mapaure, 2001a). Fire and herbivory significantly influenced small-scale variations in species composition of the miombo woodlands. Total exchangeable bases and silt significantly influenced natural floristic heterogeneity. Species composition in some woodland patches gradually changed from woodlands dominated by *Brachystegia* and *Julbernardia* species to woodland thickets dominated mainly by *Combretaceae* species (Mapaure, 2001a).

2.42 Wood cutting

Cutting, lopping or other damage to trees is a common phenomenon throughout all African savannas, whether humans or large mammals cause it (Shackleton, 2000). Felling or lopping by humans is usually more severe than the effects of damage by large herbivores, but may range from selective removal of particular individuals (species and/or sizes) within a stand (Shackleton, 1993), through to almost clear felling of an entire area (Chidumayo, 1993; Chidumayo *et al.* 1996).

Shackleton (2000) studied the influence of cutting height, stem size and surface area on the number of coppice shoots produced for twelve savanna species from a communal land in Bushbuckridge, South Africa. All species exhibited a strong coppicing ability following cutting. The number of shoots per stump was most frequently related to cutting height, although this was not always the most significant factor. The highest number of shoots per unit surface area was for *Albizia harveyii* and the least *Piliostigma thonningii.*

Woody communities subjected to harvesting are usually characterized by a change in overall community structure. Typically, there is a reduction in basal area relative to unharvested sites (McGregor, 1994). Density may be higher or lower than unharvested sites depending on the degree of coppice regrowth. According to Shackleton (1997), prolonged or intense harvesting diminishes larger size classes because of the lack of recruitment into the large-size class to replace natural senescence. Fuel wood harvesters actively select stems of particular size species (Shackleton, 1993; Mcgregor, 1994). This results in a reduction in the range of size classes represented.

In the semi-arid lands of Kenya, harvesting wood for fuel resulted in great loss of indigenous biodiversity and destruction of vital ecosystems and habitats (Kirubi *et al.* 2000). Tree density declined as a direct consequent of harvesting. Wood fuel demand also involved loss of tree species through deliberate species selection. Species were selected for wood fuel production, and consumption also depended on availability and accessibility of wood (Kirubi *et al.* 2000).

Tree regeneration and response to selective cutting of *Pterocarpus angolensis* and *Sterculia quinqueloba*, was measured outside Katavi National Park, Tanzania. Contrary to expectations, selective harvesting had no effect on tree recrutment for either species in this miombo woodland (Schwarzt and Caro, 2003).

A comparison between logged, 6-month and 18-year post harvest forest stands in a central African forest indicated the lasting effects of highly selective logging. There was little difference in tree species composition and diversity between treatments (Hall *et al.* 2003). Stem densities of both saplings and trees in unlogged forests were significantly higher than those in forests sampled 18 years after logging. Evidence suggested inadequate recruitment of the principal timber species (Hall *et al.* 2003).

3.0 Study Area

3.1 Location

Mazowe Botanical Reserve, with an area of 48 hectares, is located some 30 km north of Harare near Christon Bank Township, Zimbabwe (17^0 39'S, 31^0 31'E, Figure 3.1). It lies at an altitude of around 1400 m. The area is designated as a Botanic Reserve under the National Parks and Wildlife Act (1975). It is bordered by the Mazowe River to the east, Christon Bank Township to the west, Spelonken Estate to the north, and the southern boundary falls near the foot of the Shiva Hills (Tsvuura and Nyamhanga, 2002).

3.2 Climate

The climate can be described as seasonal, exhibiting an alternation of annual wet and dry seasons. The transition from one season to another varies considerably between years. Most of the rain is received in the summer months, from November to April. Total annual rainfall recorded at the Mazowe Dam, about 4 km to the north, is 903 mm on average, but with a high yearly variation (Tsvuura and Nyamhanga, 2002).

The mean monthly temperatures recorded at the Henderson Research Station nearby range from 12.9 ^{0}C in July to 21.6 ^{0}C in November. Mean monthly temperatures fluctuate between 20 ^{0}C and 22 ^{0}C during summer months. Winter months from May to July are cool and dry. Frequent night frosts occur during these months. The weather becomes progressively warmer from August to November when the rainy season begins (Tsvuura and Nyamhanga, 2002).

3.3 Geology and Geomorphology

The underlying geology of central and southern Africa, including a large part of Zimbabwe, is largely Precambrian, comprising mainly Archean metavolcanics and intrusive granitic gneisses of varying ages (Frost, 1996). The distribution of miombo woodland is largely coincident with the flat-to-gently undulating landscapes of the African and past-African planation surfaces. Mazowe Botanical Reserve is located within the central watershed in Zimbabwe, which is an area underlain by rocks of the basement complex i.e. intrusive granite and greenstone belts (Chenje *et al.* 1998). Within the Botanical Reserve, there are granitic hills and gently sloping plains between the hills and the Mazowe River and its tributary (Tsvuura and Nyamhanga, 2002).

3.4 Soils

Soils are kaolinitic, belonging to the paraferrallitic group, and are well drained, heavily leached, with relatively low fertility (Thomson and Purves, 1978). They consist of predominantly coarse-grained sands derived from granite. This contributes to their low fertility. The sandy para-ferrallitic soils dry out quickly at the end of the rainy season (Tsvuura and Nyamhanga, 2002). Soil moisture and temperature regimes of miombo woodland are generally ustic, meaning that soil moisture is present at a time when conditions are suitable for plant growth but is limited for at least 90 days at some time during the year (Frost, 1996).

3.5 Vegetation

Brachystegia spciformis and *Julbernadia globiflora* dominate the vegetation of Mazowe Botanical Reserve. It is mapped under deciduous miombo savanna woodland according to Wild and Barbosa (1968). Based on the total annual rainfall of >1000 mm, the vegetation can be described as dry miombo woodland (Frost, 1996). In Mazowe Botanical Reserve, vegetation can be divided into three broad types corresponding to the main topographic formations. These are the riverine fringe of the Mazowe River and its main tributary, the hill miombo of the granite kopjes, and the regularly fire-affected woodland of the gently sloping plain between the hills and the river (Tsvuura and Nyamhanga, 2002).

The riverine fringe is a dense thicket of climbers, shrubs and trees of *Celtis Africana* and *Ilex mitis* that reach up to 15-18 m high, interspaced with *Rhus lancea.* Grass is rather sparse and is dominated by *Oplismenus undualatifolias* and *Oplismenus hirtellus* (Tsvuura and Nyamhanga, 2002).

On the granite hills, *Brachystegia boehmii, Brachystegia glaucescens, Julbenardia globiflora* and *B. spiciformis* are found. *B. gloucescens* is dominant on the upper slopes (averaging a height of 10-12 m), while the lower slopes are dominated by *B. boehmii* at a height of about 8 m. The main succulents are *Aloe excelsa* and *Euphorbia griseola,* while the most abundant shrub is *Poulzolzia mixta.* The grass cover is sparse, and consists of *Hyparrhenia variabilis* and *Danthopsis pruinosa* (Mujawo, 2002; Tsvuura and Nyamhanga, 2002).

The gently sloping plain has *Monotes glaber,* frequently interspersed with *B. spiciformis* and *J. globiflora.* These trees are about 10 m high. Other characteristic woody plants are *Albizia antunesiana, Dichrostachys cinera* and *Faurea speciosa. Protea welwitschii* is a major shrub in the woodland. The stems of most mature individuals of these trees show evidence of burning, a result of previous fires (Mujawo, 2002; Tsvuura and Nyamhanga, 2002). The grass cover is more pronounced here than on the hillslopes, being largely comprised of *H. viriabilis, Themeda triandra* and *Trstachya nodiglumis.* Termite mounts occur more frequently in the woodland than on the hillslopes (Tsvuura and Nyamhanga, 2002).

3.6 Human activity

The major land-use activity near and around the Mazowe Botanical Reserve is farming. Zimbabwe's largest commercial farming sector, supporting crops such as tobacco, maize and paprika, lies within the Central Watershed within which the Botanic Reserve is located (Chenje *et al.* 1998). Illegal gold panning activities have recently been reported in the upper reaches of the Mazowe River, which is close to the Botanical Reserve (Nobanda, pers. comm.).

4.0 Method

4.1 Sampling

Stratification was carried out, after an initial reconnaissance of the area, following methods by Mueller-Dombois and Ellenberg (1974).

Steps followed in vegetation sampling were as follows:

a) segmentation of the vegetation cover or recognition of entities (i.e. entitation);
b) selection of sampling plots in the recognized segments;
c) decision of size and shape the sampling plot should take, and
d) decision on what to record once sampling plots are established (Mueller-Dombois and Ellenberg, 1974).

According to Kent and Cocker (1992), criteria for stratification can be made on the basis of growth form, physiognomy, structure, or environmental differences such as aspect, geology or slope form. Stratified random sampling of the vegetation in the Mazowe Botanical Reserve was done, and the major divisions were made primarily on the basis of differences in aspect and slope position (Kent and Cocker, 1992).

The Botanic Reserve was divided into three slope directions, namely north facing slope (N), northeast (NE) facing slope and northwest (NW) facing slope. Slope direction was measured using a compass and slope angle was determined by the use of a clinometer. Each slope direction was divided into three zones based on slope position/level, i.e. hilltop vegetation (Top slope) on the granite hills, vegetation on the gently sloping plain (Middle slope) and vegetation in the vicinity of the river (Bottom slope). Riverine vegetation was not sampled in this study.

Five quadrats were randomly laid per each slope level, using random numbers, giving a total of 15 quadrats per slope direction. Thus, the total number of sampled plots for the three aspects (N, NE and NW) was 45.

Sampling in each sub-segment (i.e. slope level) ensured coverage across the whole vegetation segment, while randomly locating of sampling sites within the sub-divisions was aimed at minimizing bias (Mueller-Dombois and Ellenberg, 1974; Sokal and Rohlf, 1995).

4.2 Demarcation of plots

In each zone, 10 x 10 m plots were demarcated for the tree layer, following methods by Campbell *et al.* (1995) in their study of miombo woodland in Marondera. The plots were located in each of the zones using random numbers (Mueller-Dombois and Ellenberg, 1974). For shrubs, a sub-plot of 5 x 5 m was randomly demarcated within the 10 x 10 m plot (Mujawo, 2002). Smaller sub-plots of 1 x1 m were also randomly demarcated within each 10 x10 m plot for grasses following general guidelines for optimum size of quadrat for selected vegetation types by Kent and Cocker (1992).

4.3 Vegetation Inventory

The following vegetation attributes were recorded on vegetation data sheets for each plot:

1. **Species name.** Trees, shrubs and grasses were identified in the field, and those, which could not be identified, were preserved in a plant press for later identification at the National Herbarium, Harare.

2. **Basal diameter**

The stem basal area is the cross sectional area of the trunk measured at the lowest point not influenced by basal swellings. Vegetation structure can be described using basal area (Husch *et al.* 2003). Basal area can be measured through the diameter at breast height (**dbh**), i.e. 1.3 or 1.5 m above the ground by the formula πr^2, where **r** equals half **dbh** (Anderson and Ingram, 1993). In savannas, where branching frequently occurs below this height, and where trees are commonly multi-stemmed, it is, however, necessary to measure the diameter at the base (Mueller-Dombois and Ellenberg, 1974; Anderson and Ingram, 1993). In the current study diameter was measured just above the basal burl.

Measurements were only taken for woody plants with a basal diameter >4 cm. Basal diameter was measured using a diameter tape, and measurements were taken just above the basal burl (Mujawo, 2002). For multi-stemmed plants, basal diameter was measured for each individual stem, and basal area calculated separately and then summed up to get total basal area for the tree (Campbell *et al.* 1995). Shrubs were taken to be woody plants with a basal diameter <4 cm.

3. **Tree height.** Height is the vertical distance between the ground and the highest living part of a plant (Anderson and Ingram, 1993). Following methods by Anderson and Ingram (1993), tree height was estimated visually to the nearest half a meter for trees taller than 5 m. Smaller trees were recorded to the nearest 0.1 m, using a ranging rod.

4.4 Explanatory variables

The following environmental variables were assessed in each of the 10 x 10 m plot.

4.41 Edaphic factors

Soil depth. This variable was measured by hammering a metal rod into the ground until bedrock was encountered at three randomly located places within each plot (Burke, 2001).

Soil physical and chemical properties. Soil samples, each comprising three random sub-samples drawn from the same randomly drawn points as those for soil depth were bulked together, from the top 10 cm in each plot using a soil auger. The soil samples were analyzed for texture, pH, N, P, K and soil moisture, following methods outlined in Anderson and Ingram (1993).

4.42 Anthropogenic factors

Fire. Evidence of fire was assessed from observing tree bark, burnt tree stumps and charred plant remains in each 10 x 10 m plot (Mapaure, 2001b; Mujawo, 2002). History of fire was obtained from the responsible authority of the Mazowe Botanical Reserve.

Woodcutting. Cutting was determined by examining cut stumps in the 10 x 10 m plots. Stumped tree species were recorded and their basal diameters measured.

4.5 Other factors

Rock cover. Rock cover was visually estimated as percentage rock cover in each of the 10 x 10 m plots.

4.6 Data Analysis

Species richness was determined by counting the total number of different species in each stratum. Species diversity was determined by calculating Shannon's index of diversity (H'). The formula used was $H' = -\Sigma p_i (\ln p_i)$, where p_i is the proportion of individuals that belong to species **i**, which is obtained by the number of individuals in species **i** divided by the total number of individuals in the sample, **ln** is the natural log (Ludwig and Reynolds, 1988).

Normality tests were performed on species diversity, species richness, basal area, soil pH, N, P K, texture and soil moisture data, to determine whether they satisfied ANOVA assumptions (Quinn and Keough, 2002). Two way ANOVA was used to test for differences in species diversity, species richness, basal area, soil pH, N, P, K, texture, and soil moisture amongst zones in each slope and amongst the three aspects. Differences in size class distributions amongst the aspect and slopes were tested using a χ^2 test (Mapaure, 2001b**).** Hierarchical Cluster Analysis (HCA) using the average linkage method (McGarigal *et al.* 2000) was performed on a matrix of plots by species, using species presence/absence data. This was done to produce a classification identifying similarities amongst plots based on species composition (Mapaure, 2001).

Two ordination techniques, Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis were used to analyze both species data and data on explanatory variables. Ordination is the collective term for multivariate techniques that arrange sites along axes on the basis of data on species composition (ter Braak, 1995).

Detrended Correspondence Analysis (DCA) (Kent and Cocker, 1992; ter Braak, 1995), an indirect gradient analysis technique, was performed on basal area data to elucidate relationships among various plant associations and underlying environmental gradients. CANOCO version 4 for Windows package (ter Braak & Smilauer, 1997) was used for this analysis. DCA produces a simultaneous ordination of rows and columns (e.g. samples and species), which maximizes the correlation between sample and variable scores. It is capable of handling, large, complex data sets, and uncovering extremely long ecological gradients (ter Braak, 1995; McGarigal *et al.* 2000). In contrast to Principal Components Analysis (PCA), DCA is not subject to arch and compression effects, and it performs particularly well when the data have non-linear and unimodal distributions (Palmer, 1993). Most ecological data are often non-linear and unimodal. The most important limitation of DCA is its sensitivity to outliers and discontinuities in the data. DCA also performs poorly with skewed variable distributions (Palmer, 1993).

Canonical Correspondence Analysis (CCA) available in CANOCO was used to explore relationships between vegetation composition and environmental variables (ter Braak, 1995). CCA is a direct gradient analysis technique, which seeks relationships between vegetation and explanatory variables. The analysis assumes a unimodal model of vegetation response to explanatory variables (ter Braak, 1987). It detects patterns of variation in the species data that can be explained 'best' by the observed explanatory variables (ter Braak, 1995; McGarigal *et al.* 2000). It is recommended that DCA (unconstrained ordination) be used whenever CCA (constrained ordination) is performed (McGarigal *et al.* 2000). Comparison of the results will provide information beyond what either analysis alone can provide.

5.0 Results

5.1 Vegetation classification

In this investigation 37 woody plant species and 33 grass species were observed in the area. Hierarchical classification separated the plots into two broad divisions, each comprising two clusters. Four interpretable floristic associations were identified (Figure 5.1). Species presence/absence data was used to produce the dendrogram (Figure 5.1).

a) ***Brachystegia spiciformis-Monotes glaber*** woodland (Cluster-1) This woodland mainly occurs on the bottom slopes of the north facing slope and the northeastern aspects. These two slopes have deep soils and are frequently affected by fire. *Brachystegia spiciformis* and *Monotes glaber* seemed to be the dominant tree species in these plots. Other common tree species included *Julbernardia globiflora* and *Protea welwtschii*. *Heteropogon contortus* and *Hyparrhenia* species dominated the grasses.

b) ***Julbernadia globiflora-Monotes*** *glaber* woodland (Cluster-2) The woodland was dominant on the mid-slopes of the northern and the northeastern slopes. Dominant tree species in this cluster were *M. glaber* and *J. globiflora*. Other common species included *Dichrostachys cinerea*, *Burkea africana* and *P. welwtschii*. Tall grass species of *Themeda trindra, Tristachya nodiglumis* and *Hyparrhenia nyassae* were the most common on these plots. The mid-slopes were subjected to anthropogenic disturbances of fire and woodcutting.

c) *Brachystegia gloucescens-Brachystegia* *boehmii* woodland (Cluster-3) The woodland was located on the top slopes, which are characterised by rockiness and shallow soils. The dominant tree species were *Brachystegia boemii* and *Brachystegia glaucescens*. Other common species included *Poulzozia* mixta and *J. globiflora.* Grasses, which dominated the top slopes, were *Digitaria milanjiana, Andropogon gayanus* and *Danthiopsis pruinosa.*

d) Brachystegia *boemii* woodland (Cluster-4) Plots in this cluster occurred on slope positions that were transitional between the top slopes and middle slopes on the three aspects. This was dominated by *Brachystegia boehmii.* Other common species included *Lannea discolor* and *Combretum molle*. The dominant grass species was *Heteropogon contortus.*

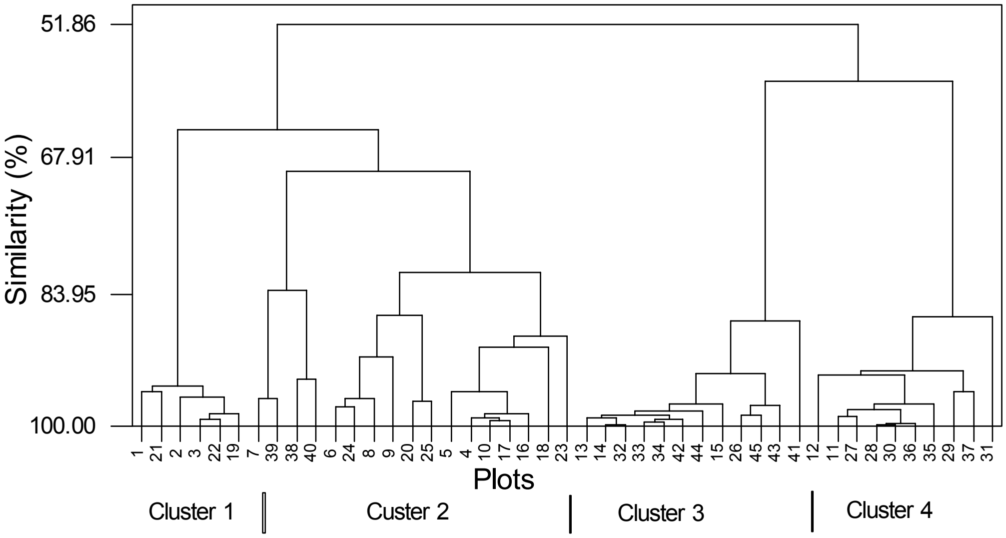

Figure 5.1. Hierarchical cluster analysis of plots from three slopes on the basis of presence/absence data of woody and grass species, in Mazowe Botanical Reserve.

5.2 Variations in vegetation structure

Size class distributions based on basal areas of all the woody species on the sampled plots showed that there were more individuals in the low basal area class (<100cm^2) than in higher basal classes, on all the slopes (Figure 5.2). The largest size class (>1000cm^2) had the least number of individual trees on all the aspects.

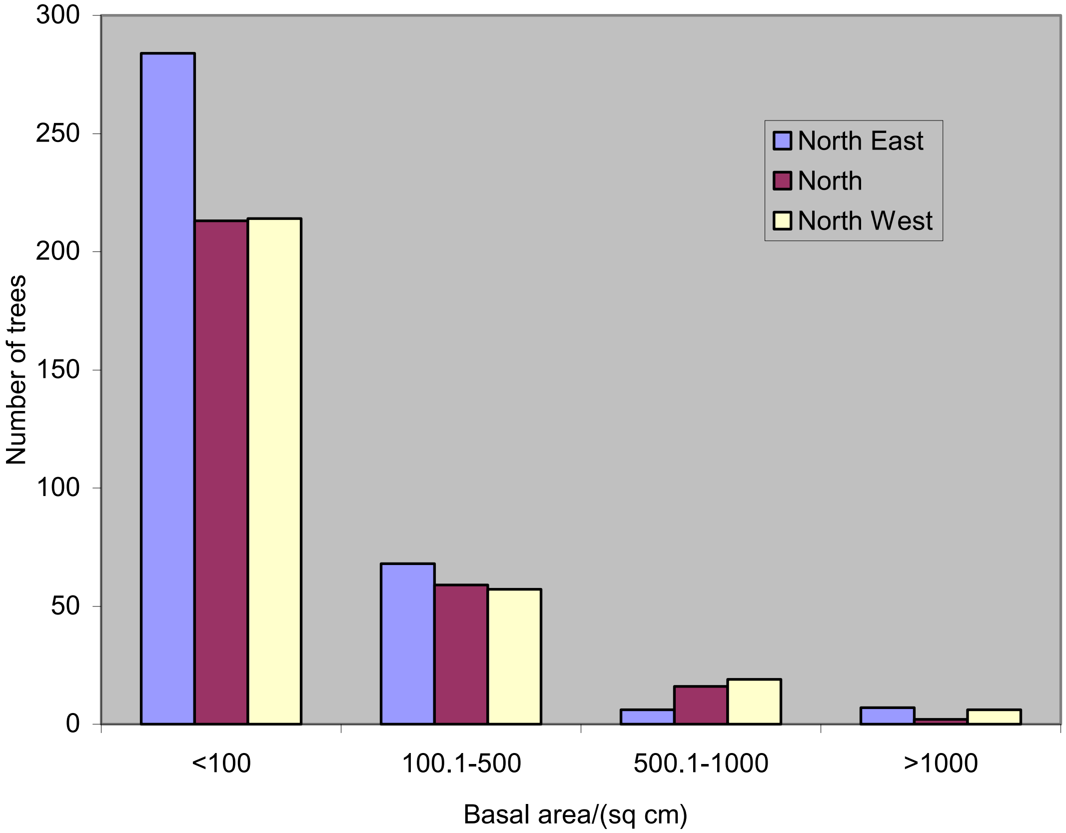

Figure 5.2. Size class distribution of woody species on the three slopes in Mazowe Botanical Reserve

The χ^2 tests showed significant differences in size class distribution of woody species amongst the three aspects (χ^2 =13.16, df =6, $p < 0.05$). The northeastern slope had the highest number of the smaller size class (<100 cm^2) trees amongst the three aspects (Figure 5.3). On all the aspects, the largest size class (>1000 cm^2) trees were few in number, and most of the very large trees such as *B. gloucescens,* occurred on the top slopes (Figure 5.3). Significant differences in size class distribution amongst slope positions along each aspect were also recorded for the northeastern aspect (χ^2 =24.44, df=6, p<0.05), the northern aspect (χ^2 =17.68, df=6, p<0.05) and the northwestern aspect (χ^2 =1346, df=6, p<0.05).

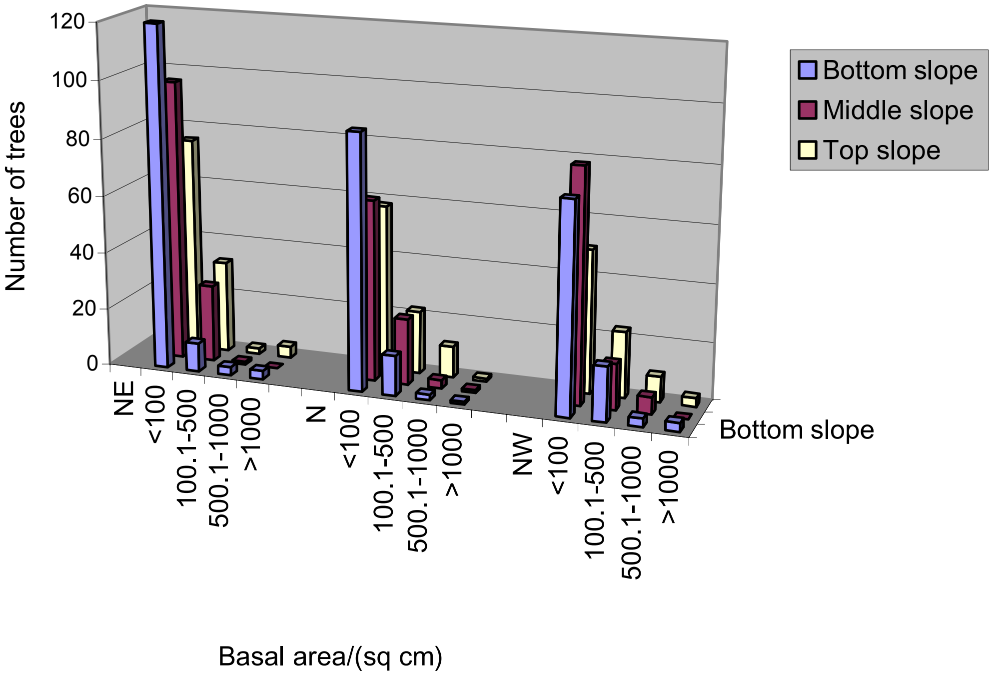

Figure 5.3. Size class distributions of woody species along the Northeastern, North and northwestern slopes in Mazowe Botanical Reserve

The most common tree species on all the slopes was *J. globiflora (*Figure 5.4). Small sized individuals (<100 cm^2) dominated by *M. glaber* and *J.globiflora,* occurred mainly on the north eastern and northern aspects. There was a notable absence of *M. glaber* in the largest size class (>1000 cm^2) and from the top slopes. The north western aspect was different from the other two aspects in that it had a higher proportion of the large tree size class (>1000 cm^2), dominated by species of *B. gloucescens* and *B. boehmii* on all the slope positions (Figure 5.4).

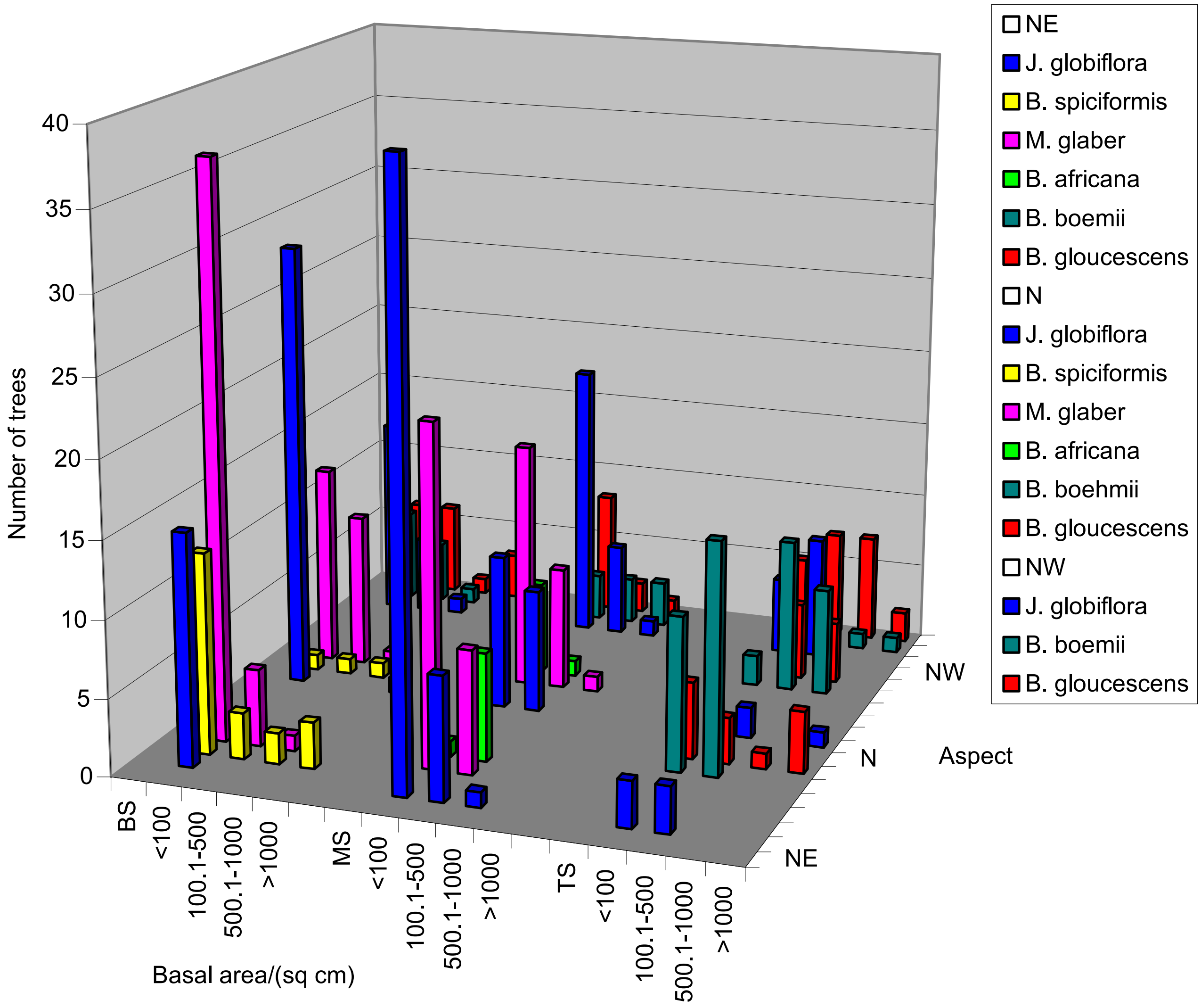

Figure 5.4. Size class distribution of the dominant woody species along the slopes in Mazowe Botanical Reserve (BS- bottom slope, MS- middle slope, TS- top slope)

5.3 Basal area

There was no significant difference amongst the aspects with respect to mean basal areas. Significant differences (F=4.59, P<0.05) in terms of mean basal area were noted amongst the slope levels (Figure 5.5). Pair wise comparison amongst the zones showed significant differences between the bottom slopes and the top slopes (F=2.71, P<0.05) and also between the middle slopes and top slopes (F=2.70, P<0.05). However, no significant differences in mean basal area were noted between the bottom slopes and middle slopes (Figure 5.5).

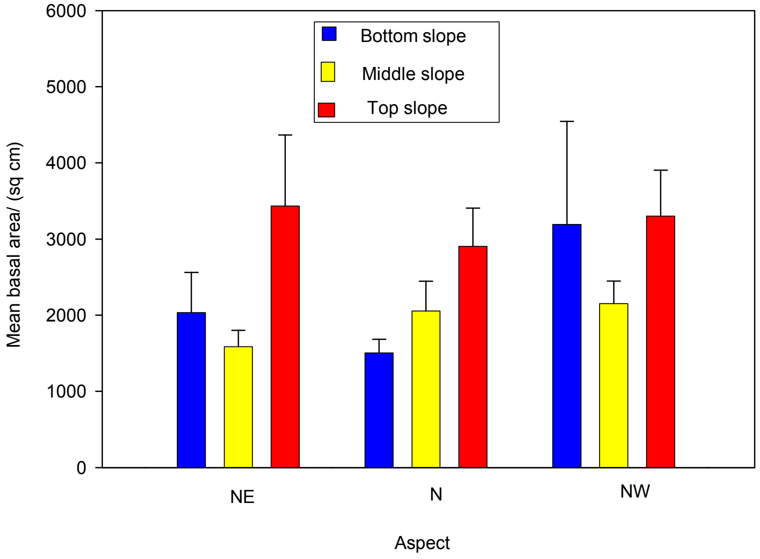

Figure 5.5. Differences in mean basal area of woody species (± SE) amongst the slopes in Mazowe Botanical Reserve

5.4 Species diversity and richness

Two way ANOVA of species richness data showed no significant differences in terms of mean species richness amongst the three aspects and amongst the slope positions. There were significant differences (F=2.49, P<0.05) in species diversity amongst the three aspects and amongst the zones (F=4.51 P<0.05). The northwestern aspect had the highest mean species diversity. The northeastern aspect was observed to be the least diverse (Figure 5.6).

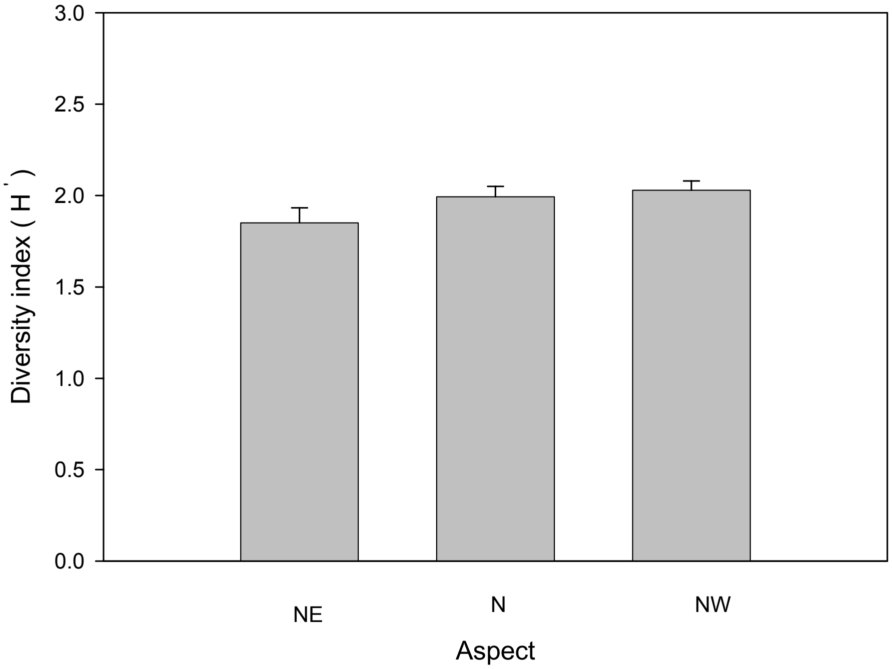

Figure 5.6. Differences in mean species diversity (± SE) with respect to aspect amongst three slopes in Mazowe Botanical Reserve

The top slopes had the highest species diversity indices. In particular the top slope on the northeastern aspect had the highest mean diversity (H'=2.3). Greater variation in diversity indices was noted in the northeastern slope as compared to the other two aspects (Figure 5.7).

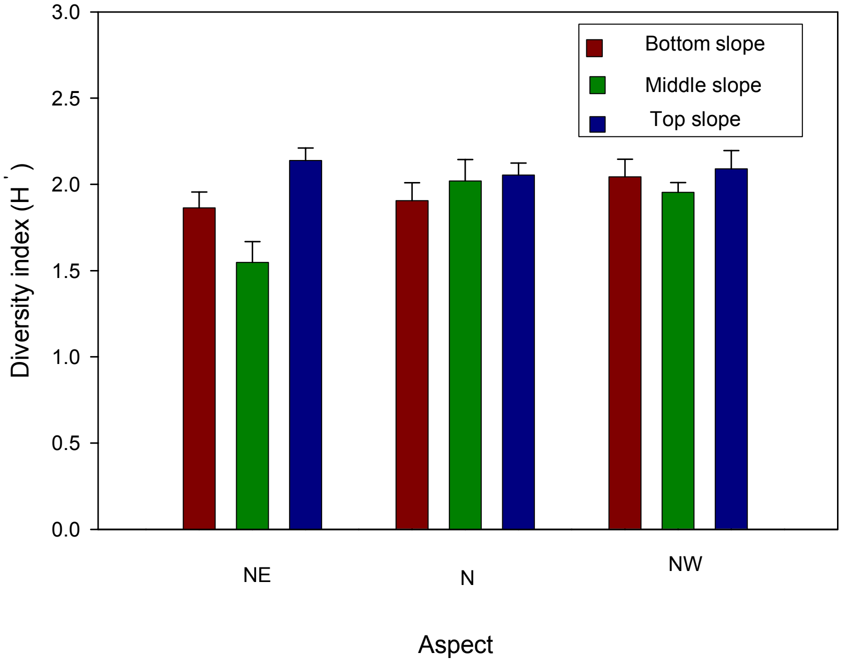

Figure 5.7. Differences in mean species diversity (± SE) amongst the different slope positions in Mazowe Botanical Reserve

5.5 Edaphic variables

5.51 Potassium

Significant differences in potassium ($F=12.05$ $P<0.05$) were recorded amongst the three aspects (Table 5.1). The northwestern aspect differed significantly in soil potassium from the southeastern and northern aspects ($F= 4.7$ $P<0.05$, $F= 3.58$ $P<0.05$ respectively). The highest levels of soil potassium were recorded on the north-western slope (Table 5.1).

Potassium (K) levels were highest on top slopes of all the three aspects. The top slopes were significantly different in terms of potassium ($F=4.53$ $P<0.05$, $F=4.52$ $P<0.05$) from the bottom and mid slopes. Among the slope positions, the top slope on the northwestern aspect recorded the highest potassium levels (Table 5.1).

5.52 Nitrogen

There were significant differences in nitrogen ($F=4.94$ $P<0.05$) amongst the slope positions. High nitrogen levels were recorded on the hill slopes. The top slope on the northeastern aspect had the highest level of soil nitrogen (Table 5.1). The bottom and middle slopes did not show significant differences in soil nitrogen. The top slopes differed significantly with the bottom and middle slopes in nitrogen content ($F=2.76$ $P<0.05$, $F=2.68$ $P<0.05$ respectively).

5.53 Phosphorus

There were also significant differences ($F=16.51$, $P<0.05$) amongst the three slopes in terms of phosphorus. The northwestern aspect recorded the highest soil phosphorus levels

(Table 5.1). There was significant difference (F=5.07 P< 0.05) in soil phosphorus between the bottom slopes and top slopes.

Table 5.1. Mean values of soil potassium, soil phosphorus and soil nitrogen for the aspects and slope levels in the Mazowe Botanical Reserve.

	Potassium (me %)			Phosphorus (ppm)			Nitrogen (ppm)		
	NE	N	NW	NE	N	NW	NE	N	NW
Bottom slope	0.32	0.35	0.54	3.4	3.6	31.8	7.4	6.6	4.8
Middle slope	0.31	0.33	0.56	7.6	4.4	11.0	5.2	6.8	6.6
Top slope	0.51	0.62	0.67	6.6	11.4	23.2	10.8	7.6	7.0
Average	0.38	0.43	0.59	5.9	6.5	22.0	7.8	7.0	6.1

5.54 Soil texture

Silt and clay content were significantly different (F=3.95 $P < 0.05$ and F=20.34 $P < 0.05$ respectively) amongst the three slopes. Silt content also differed significantly (F=5.56 $P<0.05$) amongst the zones, with the top-slopes showing the highest levels of silt. The northeastern slope had the highest levels of clay, whilst the highest levels of silt were recorded on the northwestern slope (Figure 5.8).

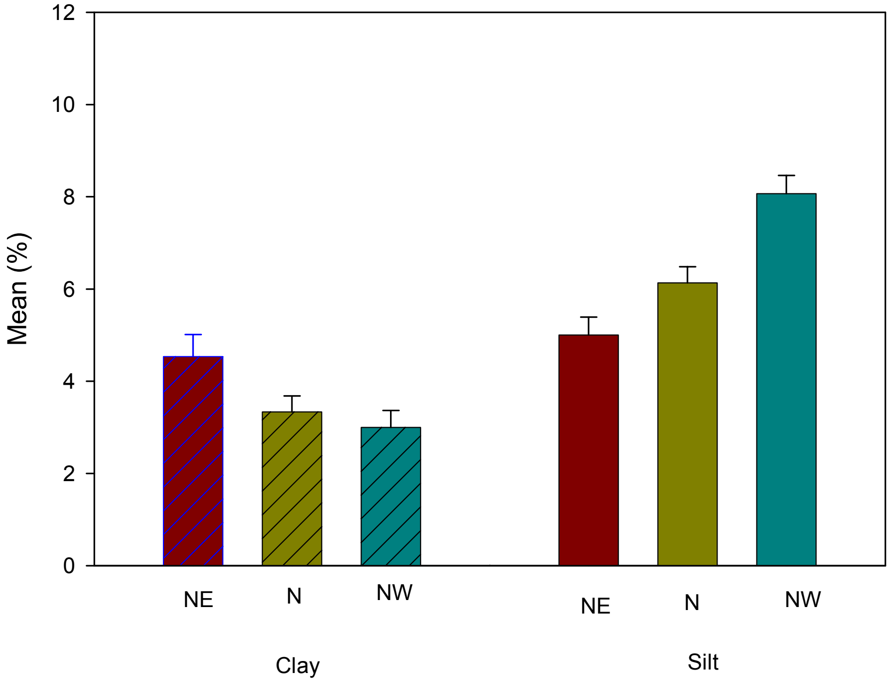

Figure 5.8. Differences in soil texture (± SE) among the slopes in Mazowe Botanical Reserve

5.55 Soil moisture

Significant differences in soil moisture (F=61.18 P <0.05) amongst the slopes were recorded. The northwestern slope had the highest levels of soil moisture content. The northern and the northeastern aspects recorded comparatively low soil moisture levels (Figure 5.9).

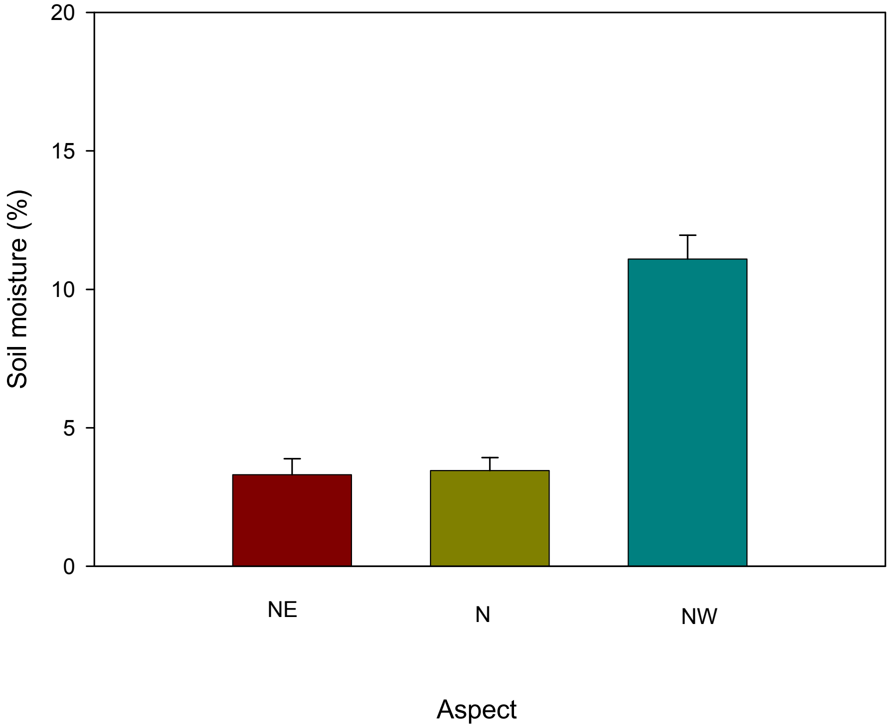

Figure 5.9. Differences in soil moisture (± SE) amongst the aspects in Mazowe Botanical Reserve

There were significant differences in soil moisture content (F= 3.56 P <0.05) between the bottom slopes and the top-slopes. The northwestern slope had the highest soil moisture content levels for all the slope positions i.e. bottom slope, middle slope and top slope (Figure 5.10).

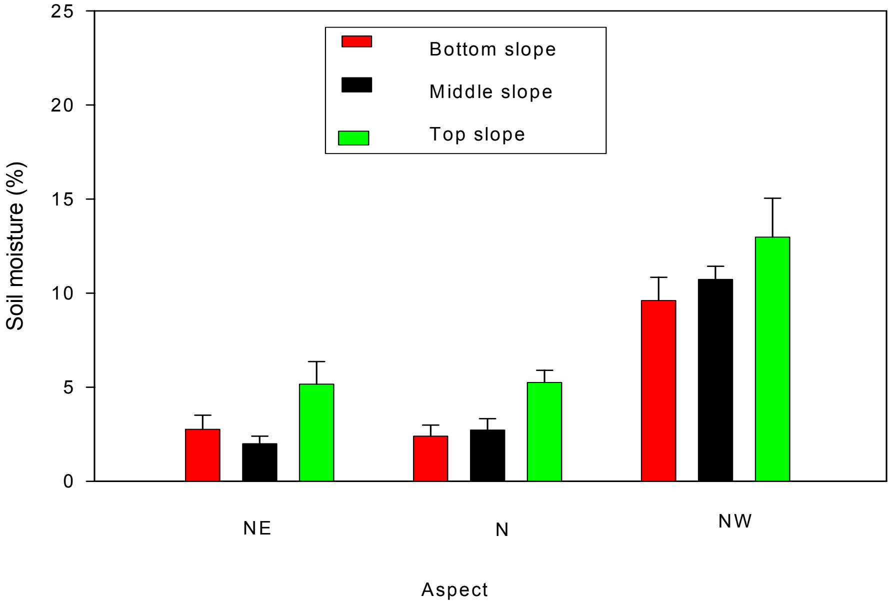

Figure 5.10. Differences in soil moisture (± SE) amongst the slope positions along the three slopes in Mazowe Botanical Reserve

5.6 Fire and woodcutting

The northern aspect was most affected by fire, and the least affected slopes were on the northwestern aspect. All the plots on the bottom and middle zones of the northern and northeastern aspects showed evidence of fire (Table 5.2). The top slope of the northeastern aspect and the middle slope of the northwestern aspect showed no evidence of fire. Evidence of cut wood stumps was more apparent on the middle slopes. The northern aspect showed the highest number of cut stumps, and the northwestern aspect had the least number of recorded cut stumps. Most of the cut stumps were in the 100.1-500-cm2-size class (Figure 5.11). The top slopes, except on the northern aspect, had no evidence of woodcutting (Table 5.2)

Table 5.2. Percentage number of plots showing evidence of fire and woodcutting on three slopes in Mazowe Botanic Reserve.

	% no of plots affected by fire			% no of plots with cut stumps		
	NE	N	NW	NE	N	NW
Bottom slope	100	100	60	80	60	40
Middle slope	100	100	0	40	80	60
Top slope	0	40	20	0	20	0
Average	67	80	27	40	53.3	33.3

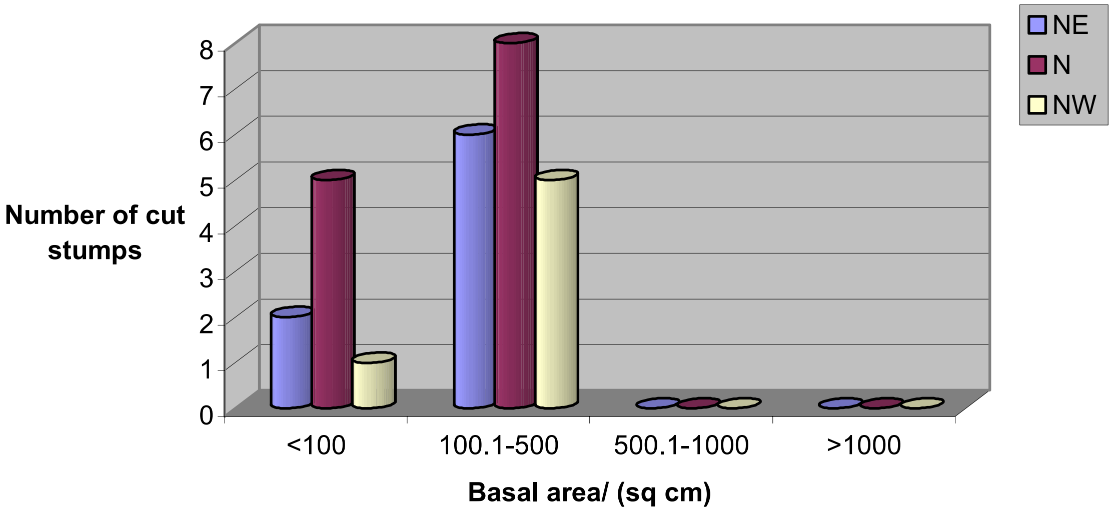

Figure 5.11. Size class distribution of cut stumps along each slope in Mazowe Botanical Reserve

A total of 29 cut stumps from six woody species were observed in the sampled area of Mazowe botanic Reserve during this study. The highest proportion of cut stumps was of *J. globiflora,* followed by *B. africana* (Figure 5.12).

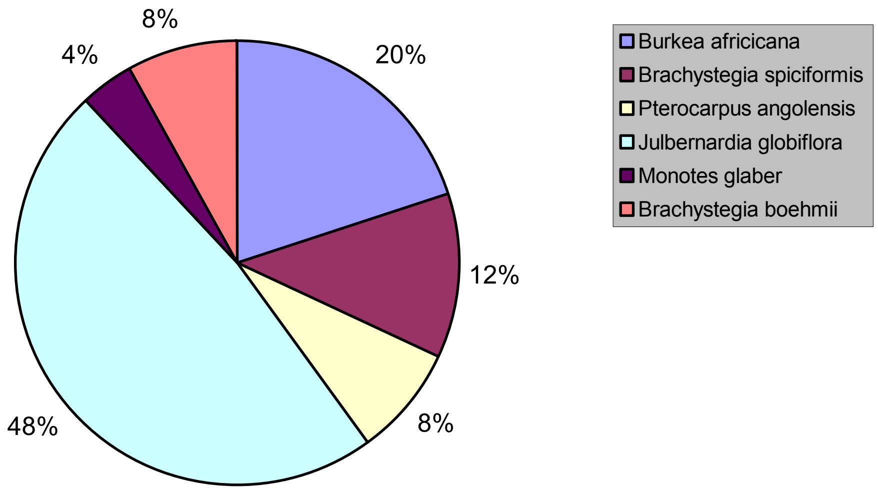

Figure 5.12. Proportions of the total number of cut stumps for selectively harvested tree species in Mazowe Botanical Reserve.

5.7 Rock cover and tree density

Rockiness characterized the northwestern slope, with the upper slope having the highest percentage rock cover compared to all other slopes (Table 5.3). The bottom and middle slopes on the north and northeastern aspects had 0 % rock cover. Rockiness was observed on the top slopes only (Table 5.3). The northeastern aspect had the highest average tree density (1240/ha) and the lowest tree density (953/ha) was recorded on the northern aspect (Table 5.3). The highest density of trees was recorded on the middle slope of the northeastern aspect, whilst the bottom slope of the northern aspect recorded the lowest density lowest amongst the slope positions (Figure 5.13).

Table 5.3. Tree density/hectare and percentage rock cover along the three slopes in Mazowe Botanical Reserve

	Tree density/ha			% Rock cover		
	NE	N	NW	NE	N	NW
Bottom slope	1260	880	1020	0	0	34
Middle slope	1340	980	1080	0	0	4
Top slope	1120	1000	1280	61.8	57	82.4
Average	1240	953	1100	20.6	19	40.1

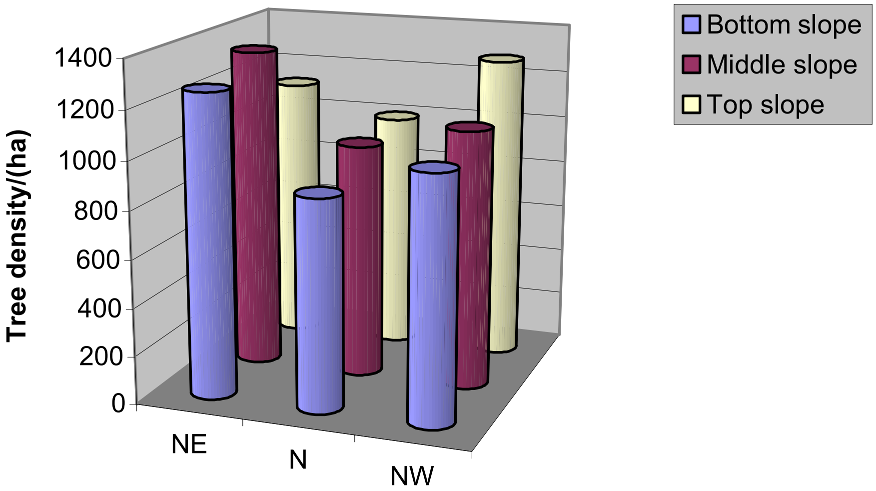

Figure 5.13. Comparison of tree density amongst the slopes in Mazowe Botanical Reserve

5.8 Main gradients in vegetation composition

The eigen values for the first two axes of the DCA were 0.783 and 0.321, respectively. These two axes explained 31.3% of the species variance (Table 5.4). Plots were separated into three main recognizable groups. These are groups I, II and III (Figure 5.14). Group 1 represented the bottom and middle slopes associated with *J. globiflora, B. spiciformis, M. glaber, T. triandra, and Hyparrhenia* species. Group II represented the steep and less rocky hillside plots, associated with *B. boehmii*, *J. globiflora* and *H. contortus*. Group III represented plots on the granite hills, with shallow soils, associated with *B. glaucescens, J. globiflora* and *D. pruinosa.* The first axis seemed to be associated with the soil depth gradient from bottom slope to the top slope with shallow rocky soils (Figure 5.14). *B. boehmii* and *B. glaucescens* dominated the top slopes, whilst the middle slopes and bottom slopes were dominated by *J. globiflora, M. glaber* and *B. spiciformis* which grow on deep soils.

Table 5.4. Summary of the detrended correspondence analysis (DCA) for Mazowe Botanic Reserve

Axes	1	2	3	4
Eigen values:	0.783	0.321	0.155	0.112
Length of gradient:	4.068	3.017	1.520	1.520
Cumulative percentage variance of species data:	22.2	31.3	35.8	38.9

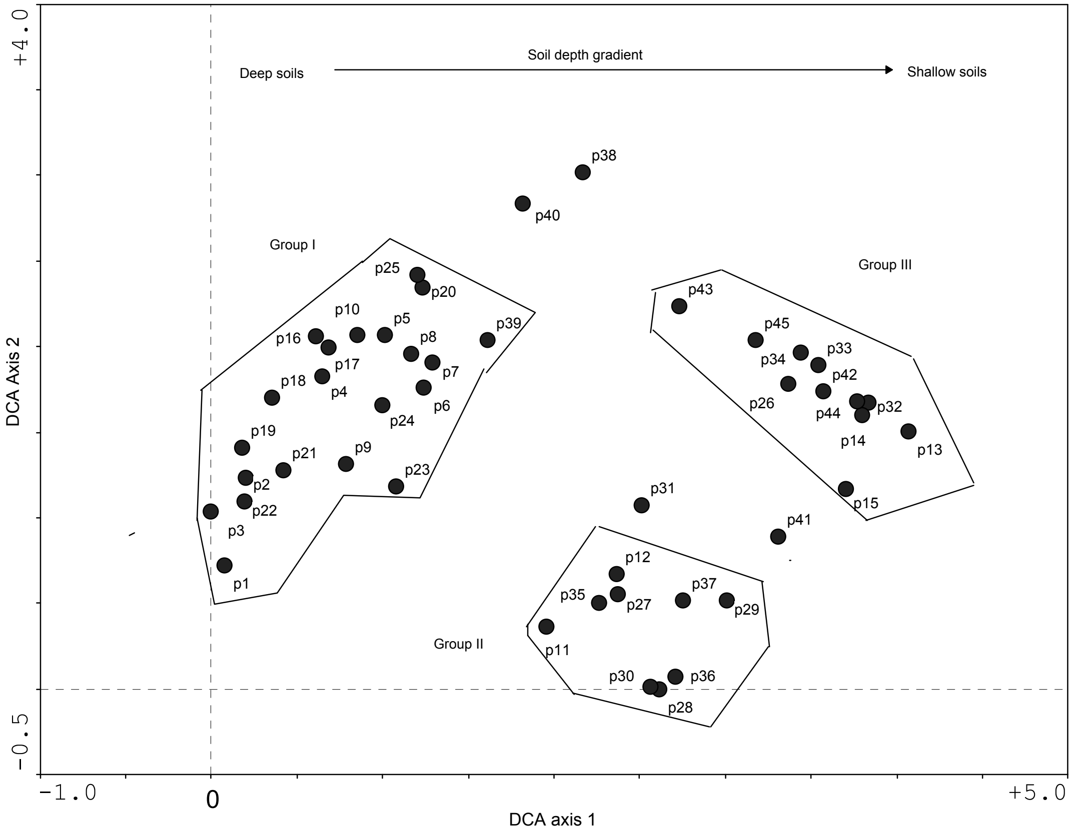

Figure 5.14. DCA ordination diagram showing the separation of vegetation plots into two main groups related to edaphic (along Axis 1) and other environmental gradients (along Axis 2)

5.9 Vegetation – environment relationships

The first four axis of the species- environmental plot accounted for 77.7% of the total variance (Table 5.5), but the main floristic-environmental patterns are indicated in a plot of axis one and two (Figure 5.15). Explanatory variables that significantly influenced species composition were soil depth ($F=9.20$, $P<0.05$), silt ($F=3.56$ $P<0.05$), pH ($F=2.80$ $P<0.05$) and (K) potassium ($F=1.88$ $F<0.05$). The influence of the following variables was insignificant: rock cover, soil moisture, sand, clay, fire, woodcutting, nitrogen, phosphorus, aspect and slope. The influence of explanatory variables along the first canonical axes was significant (F=7.46, P<0.05) and the overall test for all canonical axes was also significant (F=2.24, P<0.05). The results of the CCA technique applied to the 14 environmental variables and 37 species indicated that Axis 1 accounts for 70.1% of the observed variation in vegetation, whereas Axes 2, 3 and 4 account for 33.7%, 23.5% and 12.5%, respectively (Table 5.5).

The 45 plots were separated by inspection, into three groups (Figure 5.15). Group one (Plots 13-15,26, 32-34 and 41-45) are the plots generally found on less steep, rocky slopes with shallow soils and dominated by *B. glaucescens, J. globiflora* tree species and the grasses *D. pruinosa* and *A. gayanus*. High rock cover, soil phosphorus and sand content were important factors influencing vegetation structure, composition and species diversity in the group. Group two (Plots 11, 12, 27-30, 36, 39 and 40) are plots found on the steep and less rocky hillside slope positions. The common tree species include *B. boehmii* and *J. globiflora.* Potassium, pH and silt content were important variables influencing vegetation composition.

Group three (Plots 1-5, 6-10,16-20,21-25) is a mixture of plots from the bottom and middle slopes of the north eastern and northern aspects respectively. Most of these plots lie on deep soils (<80cm) and show evidence of anthropogenic disturbances in the form of fire and woodcutting. Soil depth and fire appeared to have more influence on vegetation composition, structure and diversity in this group (Figure 5.15). Common tree species in these plots include *B. spiciformis; J. globiflora, M.glaber, P. welwtschii,* and common grasses were *T. triandra* and A. *gayanus.*

The analysis showed that soil depth and fire were strongly positively correlated with Axis l (r =0.89 and r=0.64, respectively). On the other hand rock cover was strongly negatively correlated with axis 1 (r = -0.84). K, pH and silt were positively correlated with Axis 2 (r =0.52, r=0.47 and r=0.47, respectively).

Table 5.5. Summary of the canonical correspondence analysis (CCA) for Mazowe Botanic Reserve

Axes	1	2	3	4
Eigen values:	0.701	0.337	0.235	0.125
Species-environmental correlations:	0.951	0.758	0.787	0.857
Cumulative percentage variance of:				
Species data:	19.9	29.5	36.2	39.7
Species environmental data:	39.0	57.7	70.7	77.7

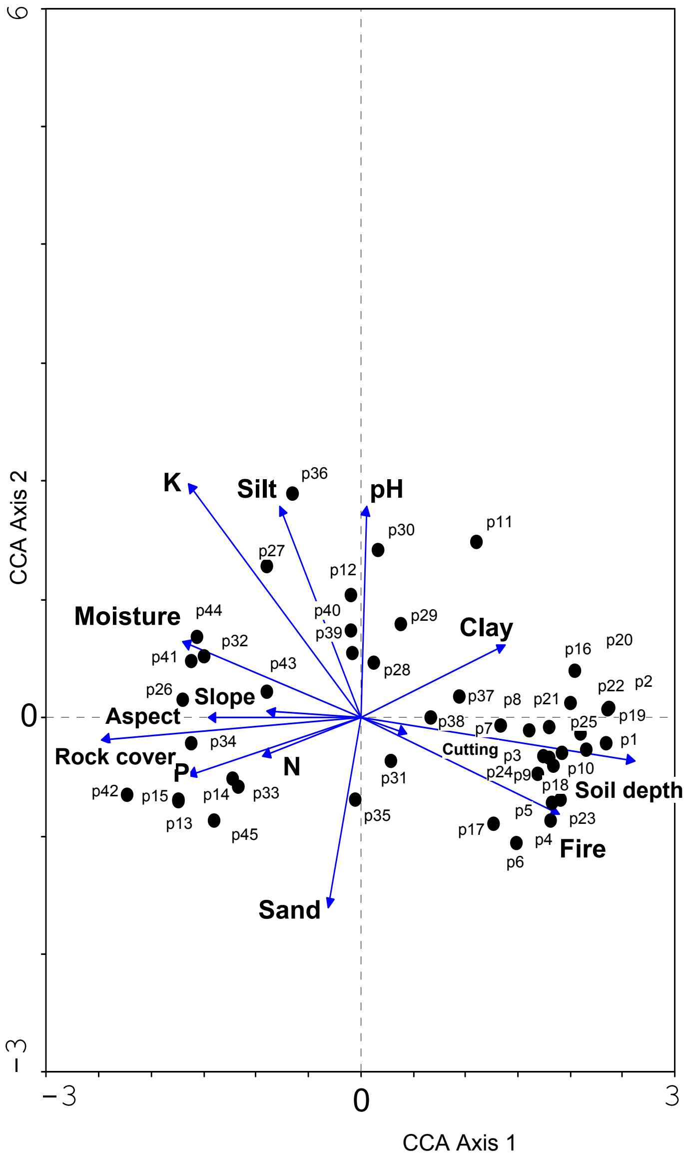

Figure 5.15. A Canonical Correspondence Analysis ordination showing the distribution of the 45 plots in relation to available environmental factors in Mazowe Botanical Reserve

6.0 Discussion and Conclusion

6.1 Vegetation classification

A study on species composition of the Mazowe Botanical Reserve revealed that the area is typical of miombo woodland as described by Wild & Barbosa (1967) and White (1983). Common tree species recorded in the course of the study included *J. globiflora, M. glaber, B. spiciformis, B. boehmii* and *B.gloucescens*. There was clear-cut separation of vegetation associations according to slope position, especially on the northeastern and northern aspects (Figure 5.1). Mujawo (2002) also noted distinct vegetation groupings on different catenal positions along the northeastern aspect. Besides aspect, grouping of plots also seemed to be a function of soil depth, soil moisture, nutrients, fire and rock cover.

The upper slopes with shallow soils and high rockiness mainly consisted of *B. boehmii* and *B. gloucescens* and the shrub species *P. mixta.* The common grass species were *D. pruinosa*, which grows among rocks and rock crevices on granite outcrops, and *D. milanjiana,* usually found in undisturbed areas (Gibbs Russel *et al.* 1990*).* According to Celander (1983) the presence of *B. boehmii* in miombo woodlands usually indicates shallow soil overlaying rock, rubble or plinthite due to the species capacity to penetrate hard soil layers.

On the middle slopes, *J. globiflora, M. glaber* and *B. africana* were the most common tree species. The deep and well-drained sandy soils of the bottom slopes supported *J. globiflora, B. spiciformis* and *M. glaber* as the most common woody species. *B. spiciformis* prefers deep soils, but is not tolerant to water logging (Celander, 1983).

Although *B. spiciformis* has been reported as commonly occurring on the upper parts of catenas, on ridges, rocky outcrops and escarpments (Celander, 1983), the current study recorded *B. spiciformis* on bottom slopes.

Fire and woodcutting can alter species composition in miombo woodlands. Species composition on the middle and bottom slopes was influenced by anthropogenic disturbances i.e. fire and woodcutting. The invasive shrub species *D. cinerea* that usually encroaches on disturbed sites (Mapaure, 2001a; Dahlberg, 2000) proliferated on some of the plots on the middle and bottom slopes. The impact of fire on plants depends on the intensity and timing in relation to plant phenology (Frost, 1996).

Changes in species composition can occur in miombo woodlands due to repeated exposure to fire resulting in a woodland dominated by fire tolerant species (Cauldwell and Zieger, 2000). In the Mazowe Botanical Reserve, *M. glaber,* a fire tolerant species (Cauldwell and Zieger, 2000), was dominant on the middle and bottom slopes, whilst the fire-tender species like *B. spiciformis* and *J. globiflora* (Cauldwell and Zieger, 2000; Frost, 1996; Grundy, 1993; Trapnell, 1959) were comparatively less prevalent. Some studies have shown that fire together with herbivory, influences small-scale variations in species composition of miombo woodlands (Mapaure, 2001a). Thus, disturbances such as fire are important drivers of vegetation change and are key determinants driving succession patterns at different scales in miombo woodlands (Mapaure, 2001b).

The northwestern aspect seemed to have single type of vegetation association characteristic of upper slope vegetation i.e. *B. boehmii, B. gloucescens* and *J. globiflora*.

There was no clear-cut separation of vegetation associations along the northwestern slope, suggesting little variation of the environmental variables influencing vegetation composition along this slope. High rockiness characterized the northwestern aspect (>40 %), and rockiness was observed on all slope levels (Table 5.3). This could have influenced species composition on the northwestern aspect as it was dominated by plant species that are able to grow on rocky terrain (Figure 5.4). The northwestern aspect was the least disturbed by fire and woodcutting, and being nearest to the guardhouse, illegal tree cutting was minimal (Table 5.2).

6.2 Vegetation structure

The size class distribution of woody species in Mazowe Botanical Reserve showed a reverse-J shape (Figure 5.2 and 5.3), which is characteristic for species with high recruitment (Hall and Bawa, 1993; Chidumayo and Frost, 1996; Lykke, 1998). Significant differences in size distributions of trees were noted in Mazowe Botanical Reserve (Figure 5.3). Vegetation structure on heavily disturbed slopes differed from that on relatively less disturbed slopes. Slope position, soil moisture, fire and woodcutting seemed to have a significant influence on vegetation structure in the Botanic Reserve.

Size class distributions of some of the woody species on the bottom and middle slopes (Figure 5.3) were dominated by small trees (<100cm^2), which indicated the potential for high regeneration (Chidumayo *et al.* 1996). The upper slopes supported tall (10-20 m) and large sized (>1000 cm^2) trees and these were mostly *B. boehmii* and *B. glaucescens*. Tree height and basal area appeared to be related to soil moisture availability (Frost, 1996). Top slopes, with relatively higher soil moisture levels (Figure 5.10), recorded the largest and tallest trees (Figure 5.3). The relatively dry middle and bottom slopes supported smaller trees.

Woodcutting was prevalent on the bottom and middle slopes and results of the current study seemed to indicate preferential cutting of trees according species and size (Figure 5.11 and 5.12). Woody communities subjected to harvesting are usually characterized by a change in community structure. McGregor (1994) reported a reduction in tree basal area in harvested sites relative to unharvested sites in miombo woodland. Findings from the current study showed lower basal areas on the bottom and middle slopes as compared to the top slope where cutting was minimal.

The deliberate selective cutting of tree species of certain sizes is usually the predominant form of harvest for specific wood products like fuel wood, timber and materials for farm tools (Chidumayo, 1996). Many miombo trees can be used for firewood, but certain species are selected for their burning qualities (McGregor, 1994). In Mazowe Botanical reserve *J. globiflora,* which had the highest proportion of cut stumps (Figure 5.12), showed a reduction in the range of size classes especially on the heavily disturbed bottom and middle slope of the northern aspect (Figure 5.4).

Prolonged selective harvesting could have led to the disappearance of the large size classes (>1000cm^2), for *J. globiflora* and *B. Africana* on the middle and bottom slopes in Mazowe Botanical Reserve (figure 5.4). According to Shackleton (1997), prolonged or intense harvesting can result in a lack of recruitment into the large-size classes to replace natural senescence.

Fire is an important ecological factor in miombo woodlands (Chidumayo, 1988; Cauldwell and Zieger, 2000). In addition to changes in species composition fire can cause changes in vegetation structure (Frost, 1996). Fire can be a principal agent in suppressing regeneration and crippling young stems (Chidumayo *et al.* 1996). The middle and bottom slopes of the northern and northeastern aspects in the Botanical Reserve were the most fire affected and the northwestern aspect was the least fire affected (Table 5.2).

Effects of fire on woody vegetation are influenced by several interacting factors: timing and frequency of burning, type of fire, and fire intensity (Frost *et al.* 1986; Frost and Robertson, 1987; Bond and van Wilgen, 1996). The highly fire affected middle and bottom slopes had lower mean basal areas as compared to the top slopes which were less affected by fire (Figure 5.5). Shackleton (1997) reported a decrease in basal area with increasing fire frequency in Southern African savanna woodlands. Thus, overall woodiness tended to be high in areas least affected by fire (Shackleton, 1997). Relatively large mean basal areas were recorded on the less fire affected top slopes. Tree size generally increased as one moved up from the bottom to the top slope (Figure 5.5). Grundy (1995) observed that four-year-old trees that had been burnt produced significantly less basal area than unburnt trees of the same age in Zimbabwe. This negative effect of fire on basal area seemed to be evident on fire affected slopes in Mazowe Botanical Reserve.

The impacts of fire vary among woody species and within species among size classes (Robertson, 1984). On the fire affected bottom and middle slopes of the northern aspect, the size class distribution curves of *M. glaber* and *B. spiciformis* were typically J-shaped (Figure 5.4). Geldenhuys (1996) suggested that in miombo woodlands, the typical J-shaped size class distribution might indicate that a species is fire tolerant and responds well to uncontrolled fires. On the other hand, the more fire-tolerant *B. africana* did not show the typical inverse J-shaped size class distribution (figure 5.4). This could be due to the effects of selective cutting of *B. africana* because of its high wood quality.

Stem mortality of *M. glaber* was observed on the bottom and middle slopes of the northern aspect. The relatively low basal area and tree density on the bottom and middle slopes of the northern aspects could be explained by the high mortality of *M glaber* since it was one of the dominant tree species. Man made dry season fires in miombo have been reported to cause considerable stem mortality, especially in regrowth areas (Chidumayo, 1988). Fierce fires occur during the late dry season because of the high quantities of extremely dry litter biomass (Trapnell, 1959; Chidumayo *et al*. 1996). The combination of fire and woodcutting could have contributed to high stem mortality on the disturbed plots. According to Chidumayo *et al.* (1996), the high amount of wood debris in recently cut areas may even cause early dry season fires to be fierce and damaging to young regeneration.

The tolerance or susceptibility of miombo plants to disturbance is a function of their form, developmental stage, size, physiological condition and phenological state at the time of burning (Frost, 1996).

6.3 Species Diversity and Richness

Significant differences in mean species diversity were recorded amongst the aspects and slopes in the Mazowe Botanical Reserve (Appendix 2, Figure 5.6 and 5.7). The aspects and slopes differed significantly in edaphic variables like soil moisture, texture and nutrients (Table 1, Figure 5.8- 5.10). These differences in edaphic variables might explain the differences in mean species diversity amongst the slopes. Globally, it has been hypothesized that the composition, structure and dynamics of savannas depend primarily upon the extent of the limitation and degree of variation in plant available moisture and nutrients (Skarpe, 1992).

The northwest aspect had the highest species diversity. This could be attributed to the high habitat heterogeneity on its rocky slopes. It seemed that as rock cover increased (Table 5.3), there was an increase in species diversity (Figure 5.6 and 5.7). According to Menaut *et al.* (1995), habitat heterogeneity significantly increases diversity. High mean diversity indices of the upper slopes could be due to a variety of micro sites for species establishment. The top slope of the northeastern aspect had the highest diversity amongst all the slope positions indicating the increased variety of habitats in this rocky area (Figure 5.7).

In the savanna biome, dynamic processes occur over different spatial and temporal scales in relation to the heterogeneity of environmental conditions. Such processes may be successional, stochastic or interactive and lead to a variety of vegetation structures that vary in space and time (Menaut *et al.* 1995). There were significant differences in species diversity between the most disturbed and the least disturbed sites in the botanical reserve. The northern aspect, the middle slope and bottom slopes of the northeastern aspect were relatively the most disturbed in comparison to the relatively undisturbed northwestern aspect and the top slopes (Table 5.2).

Influence of disturbance on a community depends on the frequency with which gaps are opened up. The intermediate disturbance hypothesis proposes that the highest diversity is maintained at intermediate levels of disturbance (Connell, 1978; Begon *et al.* 1996; McKinney and Schoch, 1996). Findings from the current study seemed to contradict the predictions of the intermediate disturbance hypothesis. The least disturbed northwestern aspect recorded the highest species diversity, the highly disturbed northern aspect recorded intermediate levels of species diversity, whilst the moderately disturbed northeastern slope had the lowest species diversity (Figure 5.7 and Table 5.2). Schwilk *et al.* (1997), obtained similar results in the fynbos. Species diversity was highest at the least frequently burnt sites and lowest at the sites of moderate and higher fire frequency (Schwilk *et al.* 1997).

Chidumayo (2004) observed that increases in fire frequency and intensity resulted in reduced tree richness in miombo woodlands. Perhaps the lower species diversity of the bottom and middle slopes on the northern aspect in Mazowe Botanical Reserve could be due to frequent fires of high intensity. Not all woody species are equally sensitive to fire. The dominance of the fire tolerant *M. glaber,* and the presence of other fire tolerant tree species like *Protea welwtschii*, *B. africana* and *Pterocarpus angolensis* on bottom slopes of the northern and northeastern aspects could be the result fire influences on species composition and diversity (Figure 5.4). Repeated exposure to fire can convert miombo woodland to open woodland of fire tolerant trees with tall grasses (Chidumayo, 2004; Cauldwell and Zieger, 2000; Gambiza *et al.* 2000).

Contrary to the findings of the current study, Arvind and Jeet (2005) reported that disturbances decreased the dominance of single species and increased plant biodiversity, by mixing species of different successional status, in Indian forests. Species richness and diversity for all vegetation layers were higher in high disturbance forests (Arvind and Jeet, 2005). In Mazowe Botanical Reserve, species diversity was highest in the low disturbance areas (Figure 5.7).

Anthropogenic disturbances could have increased the susceptibility of the northern middle slope to invasion to the shrub species *Dichrostachys cinerea*. Disturbed communities are susceptible to invasion according to the invasibility theory (Davies *et al.* 2000). The proliferation of *D. cinerea* on fire-affected sites on the northern aspect in Mazowe

Botanical Reserve seemed to be promoted by disturbance. Mapaure (2001a) also noted that *D. cinerea* was common in heavily damaged, fire prone sites of miombo woodlands in Sengwa, Zimbabwe. Encroachment of *D. cinerea* into disturbed vegetation has been reported in northeastern Botswana (Dahlberg, 2000).

Although miombo woodlands are said to be resilient to disturbances (Chidumayo and Frost, 1996; Chidumayo, 2004), continued widespread clearance might compromise the status of Mazowe Botanical Reserve as a biodiversity protected area (Burgess *et al.* 2004). According to Chidumayo and Frost (1996), because of the low dispersability of miombo tree species, they may not easily reinvade highly disturbed areas. This makes the recovery of woodland slow and uncertain.

6.4 Vegetation-Environmental Relationships

Strong vegetation-environmental relationships were shown to exist in the Mazowe Botanical Reserve by the current study. Species were grouped into distinct communities with varying degrees of spatial overlap or numbers of shared species (Figure 5.1, 5.14 and 5.15). Much of the variation in species composition was explained along the first DCA ordination axis, which was associated with a soil depth gradient (Figure 5.14). From the DCA ordination diagram (Figure 5.14), plots were separated along a soil depth gradient. Plots on deep soils were found on the left of the diagram, while plots with shallow soils were on the opposite end.

Edaphic variables, mainly soil depth, silt texture; soil moisture and soil nutrients explained much of the variation in vegetation composition in Mazowe Botanical Reserve (Figure 5.15). Vegetation groupings on the top slopes differed from those of the bottom and middle slopes and this could be attributed to the different edaphic conditions on these slopes (Figure 5.8-5.10). *B. glaucescens* and *B. boehmii* dominated the upper slopes with shallow rocky soils. The frequently burnt bottom and middle slopes with deep soils were dominated by *J. globiflora*, *M. glaber* and *B. spiciformis*. The growth potential of trees is affected by the amount of soil occupied by the roots, and the availability of soil water and nutrients in this space (Barnes *et al.* 1998*)*. Effective soil depth may be limited by the occurrence of rock near the surface.

One of the key determinants of savanna structure and functioning is available soil moisture (Gambiza, 2001). Soil depth influences soil water holding capacity (Solbrig, 1993) and ultimately moisture availability. Thus, vegetation composition and diversity in Mazowe Botanic Reserve could be explained along a soil depth gradient acting as a surrogate for soil moisture. Although soil moisture did not show significant influence on vegetation structure and composition in the present study, some studies have shown that edaphic factors control ecosystems through soil moisture balance (Tinley, 1982; Scholes and Walker, 1993; Solbrig, 1993; Gambiza, 2001). Tinley (1982) observed that species composition was influenced by such edaphic factors as nutrient status, pH, salinity and texture, with soil moisture being the overwhelmingly important factor.

The interactive influence of a marked alternating wet and dry season, with well-drained soils, characteristic of the vegetation type at Mazowe Botanic Reserve, influences the morphofunctional responses of plants and the functioning of the ecosystem (Sarmiento, 1984). Soil physical characteristics that influence permeability and moisture retention have profound influence on seasonal patterns of moisture availability at different soil depths (Goldstein and Sarmiento, 1987). Large water surplus during the rainy season, together with free water movement through the soil, promotes a downward movement of ions and clay that results in a rapid impoverishment of the soil nutrient content.

Sandy soils have high infiltration capacity (Frost *et al.* 1986) and in high rainfall areas, excess water drains rapidly down to the subsoil. The subsoil can remain moist throughout the year depending on the amount of moisture percolation and soil profile. Deep-rooted plants can utilize this moisture, often well into the dry season.

Plant available moisture (PAM) and available nutrients (AN) are primary determinants of Savannas. The patchy distribution of soil types and topographic features modify PAM and AN (Scholes, 1991and Solbrig, 1993). These factors, together with fire and herbivory, determine the density of the tree layer, the productivity of the system, and the rates of nutrient and water flow through the system.

Miombo woodland soils are typically acidic, have low cation exchange capacities (CEC), and are low in nitrogen, exchangeable cations (total exchangeable bases:TEB) and extractable phosphorous (Frost, 1996). Soils on the bottom and middle slopes of the northern and northeastern aspect were generally infertile as shown by their relatively low nitrogen and phosphorus (Table 5.1). Phosphorus and nitrogen play a central role in limiting primary production in tropical savannas (Breman and de Wit, 1983).

Relatively low levels of soil nitrogen on the bottom and middle slope could be due to pyrodenitrification as a result of repeated burning (Scholes and Walker, 1993). The presence of ectomycorrhizae in the roots of *B. spiciformis* and *J. globiflora* may enable them to out compete other woodland species on these infertile porous soils (Hogberg, 1992). Ectomycorrhiza may be important in enabling plants to take up phosphorus directly from organic matter in phosphorus-deficient soils (Frost, 1996).

Potassium is a major soil nutrient and is an important cation in the soil (Foth, 1984). The greatest influence of pH on plant growth is its effect on nutrient availability. When the base saturation is less than 100%, an increase in pH is associated with an increase in calcium and magnesium (Foth, 1984).

There were differences in soil texture amongst the aspects with the northwestern aspect recording the highest silt content (Figure 5.8). Soil texture influences plant available moisture and plant available nutrients. According to White (1997), soil texture is a useful indicator of soil permeability, soil water retention capacity, and soil capacity to retain cations.

Relationships between vegetation and soil have also been documented for specific conditions in various parts of Zimbabwe. Vegetation-soil relationships can express some fine differences in edaphic conditions (Kanschik and Becker, 2001). The *Brachystegia* species common in the Mazowe Botanic Reserve are associated with a variety of soils. In the relatively high rainfall regions, the governing soil condition is drainage. These species occur only on those sites where the soil is well drained (Nyamapfene, 1988).

Vegetation studies on the northeastern slope showed that tree species composition and diversity varied along a catena (Mujawo, 2002). In the current study, catenary variation in woody vegetation was noted on the northern and northeastern aspects. According to Campbell *et al.* (1995), miombo woodland exhibits heterogeneity, which becomes more apparent on hilly and escarpment terrain.

Rock cover was also an important influence of vegetation composition in the Botanic Reserve. It was negatively correlated with soil depth, and positively correlated with aspect and slope (Figure 5.15). There were notable differences between the vegetation on the rocky upper slopes and the vegetation of the bottom and middle slopes. Vegetation on the rocky northwestern aspect differed from that of the northern and northeastern aspects.

Fire was also an important factor on vegetation composition in the Mazowe Botanic Reserve (Figure 5.15). Many workers have documented the influence of fire on species composition (Trapnell, 1959; Frost and Robertson, 1987; Cauldwell and Zieger, 2000;

Gambiza *et al.* 2000; Mapaure, 2001b; Chidumayo, 2004). Impact of fire on plants depends on the intensity and timing in relation to plant phenology (Frost, 1996).

CCA showed that the variation in environmental factors to which the vegetation responded, could be predicted from a combination of a few environmental variables. The principal gradient was one of change from shallow to deep soils, with an opposite change in rock cover (Figure 5.15). The second gradient was described by potassium, pH and silt content. The Monte-Carlo permutation test showed significant differences in floristic composition in relation to environmental variables ($p<0.05$).

Soil depth, potassium, silt and pH significantly influenced species composition in the Mazowe Botanical Reserve (Appendix 3). Strong correlation of vegetation groupings with soil depth, silt content, pH and potassium revealed the possible importance of edaphic variables in influencing vegetation composition and diversity. Floristic variations of Southern African savanna woodlands show a general correspondence to topo-edaphic variation at local scales (Coughenour and Ellis, 1993; Witkowski and O'Connor, 1996; Breebaart *et* al. 2001; Siebert *et al.* 2002).

6.5 Conclusion

Physiographic factors (slope and aspect) appeared to have no pronounced effect on vegetation structure, composition and diversity in the Reserve. This may be due to the fact that slope and aspect are indirect variables, as opposed to direct variables like nutrients and pH, which directly affect plant growth.

Anthropogenic disturbances (fire and woodcutting) appeared to be more important in structuring vegetation but did not have significant influence on species composition in Mazowe Botanical Reserve.

The present study showed that edaphic variables, particularly soil depth, were the major determinants of vegetation structure, composition and diversity of vegetation in Mazowe Botanical Reserve.

6.6 Recommendations

The Mazowe Botanic Reserve is currently managed as a preserved area, which is under protection, but surrounding communities carry out illegal cutting of tress in the Botanic Reserve. Perhaps involving surrounding communities in its management might help to minimize loss of biodiversity in the Botanical Reserve. It is recommended that management of the Mazowe Botanic Reserve should include making an inventory of the possible alternative stages of its vegetation and conservation approaches must recognize the dynamism of its ecosystems.

The influence of herbivory on vegetation in the Botanic Reserve was not investigated in the current study; it can be an area of further research.

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APPENDICES

Appendix 1.

List of plant species occurring in Mazowe Botanical Reserve (Source: National Herbarium Database. Plants written in bold font were encountered during this study)

MONOCOTYEDONS

1. Adiantum capillus-veneris L.
2. Aerangis verickii (De Wild.) Schltr
3. Aloe excelsa Berger
4. **Andropogon gayanus Kunth**
5. Ansellia Africana Lindl.
6. Aristida junciformis Trin. & Rupr. Subsp junciformis
7. Arthropteris orientalis (Gmel) Posth.
8. Asparagus africanus Lam
9. Asparagus aspergillus Jessop.
10. Bulbostylis mucronata C.B. Cl.
11. Calyptrochilum christyanum (Rchb. F.) Summerh.
12. Carex spicato-paniculata C.B. Cl.
13. Chloris pycnothrix Trin
14. Chlorophytum longifolium (A. Rich.) Schweif
15. Cyperus albostriatus Schrad.
16. Cyperus angolensis Bock.
17. Cyrtorchis praetermissa Summerh subsp. Praetermissa
18. **Danthoniopsis pruinosa Hubb**.
19. Dioscorea hirtiflora Benth
20. Dryopteris incisum Forssk.
21. Equisetum ramosissium Desf
22. Eragrostis moggii De Winter
23. Eragrostis racemosa (Thunb.) Steud.
24. Eragrostis sclerantha Nees subsp. Villosipes (Jedw.) Launert
25. Eulophia livingstoniana (Rchb. f.) Summerh.
26. Eulophia longisepala Rendle
27. Eulophia milnei Rchb.f.
28. Eulophia petersii (Rchb. f.) Rchb.f.
29. Habenaria amoena Summerh.
30. Habenaria myodes Summerh.
31. Habenaria nyikana Rchb. F*****
32. Habenaria stylites Rchb.f. & S. Moore subsp.rhodesiaca Summerh.
33. **Hyparrhenia variabilis Stapf**
34. Melinis ambigua Hack subsp. Ambigua
35. Meelinis longiseta (A. Rich.) Zizka subsp. Longiseta
36. Melinis minutiflora P. Beauv.
37. Melinis tenuissima Stapf
38. Microcoelia glubulosa (Hochst.) L. Jonsson
39. Nervilia kotschyi Sch(Rchb.f.) Schltr var. purpurata (Rchb.f. & Sond.) B. Petterson
40. Oplismenus hirrtellus (L.) P. Beauv.
41. Panicum macimum Jacq.
42. Pellaea boivinii Hook
43. Pellaes calomelanos (Swartz) Link
44. Pellaea dura (Willd.) Hook.
45. Pennisetum macrourum Trin.
46. Phragmites mauritianus Kunth
47. Pogonarthria squarrosa (licht.ex Roem. & Schult.) Pilg.
48. **Rottboellia cochinchinensis** (Laour.) Clayton
49. Selaginella dregei (Presl) Hieron
50. **Setaria pumila (Poir.) Roem. & Schult**
51. Sorghastrum bipennatum (Hack.) Pilg.
52. Stereochlaena cameronii (Stapf) Pilg
53. **Themeda triandra Forssk.**
54. **Tristachya nodiglumis K. Schum.**

55. Xerophyta equisetoides Bak.

DICOTYLEDONS

1. Acacia goetzei Harms. Subsp. Microphylla Brenan
2. Acacia karoo Hayne
3. Acacia polycantha Willd.
4. Acacia rehmanniana Schinz
5. Acacia sieberiana DC
6. Acalypha allenii huch.
7. Achyranthes aspera L.var. sicula L.
8. Acokanthera oppositifolia (Lam.) Codd
9. Adenia gummifera (Harv.) Harms
10. Aeschynomene trigonocarpa Bak. f.
11. Agathisanthemum bojeri Klotzsch var. bojeri
12. Ageratum conyzoides L.
13. Albizia amara (Roxb.) Boiv.
14. Albizia antunesiana Harms
15. Alchemilla cryptantha A. Rich.
16. Allophylus africanus P. Beauv.
17. Ampelocissus Africana (Lour.) Merrill
18. Annona stenophylla Engl. & Diels
19. Annona stenophylla Engl. & Diels
20. Antidesma venosum Tul.
21. Anthraxia rosmarinifolia (sch.Bip) Oliv. Hiern
22. **Azanza garckeana (F. Hoffm.) Excell & Hillcoat**
23. Barleria crassa CB. Cl.
24. Bauhinia petersiana Bolle
25. Berkheya zeyheri (sond. & Harv.) Oliv. & Hiern
26. Bidens pilosa L.
27. Biophytum petersianum klotzsch
28. Blumers crispate (Vahl) Merxm.
29. Bobgunnia madagascariensis. J.H. Kirkbr. & Wiersema
30. Boscia salicifolia Oliv.
31. **Brachystegia boehmii Taub.**
32. **Brachystegia glaucescens Burtt Davy & Hutch.**
33. Brachystegia utilis Burtt Davvy & Hutch
34. **Brachystegia spiciformis Benth**.
35. Bridelia cathartica G. Bertol. F.subsp. melanthesoides (Baill) J. Leonard
36. **Burkea Africana Hook**.
37. Cardiospermum grandiflorum Swartz
38. **Cassia abbreviata Oliv**.
39. Cassine aethiopica Thunb.
40. Cassine matabelicum (loes.) Steedman
41. Catha edulis Forsk. & Endl.
42. Catunaregum spinosa (Thunb.) Tirveng. Subsp. Spinosa
43. Celtis Africana Burm.f.
44. Chamaecrista rotundifolia (Pers.) Greene
45. Chionanthus battiscombei (hutch) Stearn
46. Cissus cornifolia (Bak.) Planch.
47. Clematopsis villosa (DC.) Hutch.
48. Clerodendrum myricoides (Hochst.) Vatke
49. Combretum collinum Fresen
50. Combretum elaegnoides Klotzsch
51. Combretum erythrophyllum (Burch.) Sonder
52. **Combretum hereroense Schinz**.
53. Combretum imberbe Wawra
54. **Combretum molle R.Br.ex G.Don**
55. Combretum mossambicense (Klotzsch) Engl.
56. Combretum zeyheri Sond.
57. Commiphora Africana (A. Rich.) Engl.
58. Commiphoramarlothii Engl.
59. Cimmiphora mollis (Oliv.) Engl.
60. Commiphora mossambicensis (Oliv.)Engl.
61. Commiphora pyracanthoides Engl.
62. Corchorus Kirkii N.E. Br.
63. Crassocephalum rubens)Juss.ex Jacq.) S. Moore
64. Crotalaria bequaertii Bak.f.
65. Crotalaria virgulata Klozsch subsp. Longistyla (bak.f.) Polhill
66. **Cussonia arborea Hochst. Ex A. Rich**.

67. Cyphostemma buchananii (Planch.) Descoings ex Wild & Drumm.
68. Cyphostemma rhodesiae (Gil & Brandt) Descoings ex Wild & Drumm.
69. **Dalbergia nitidula Bak**.
70. Desmodium salicifolium (Poir.) DC.
71. Desmodium uncinatum (Jacq.) DC>
72. **Dichrostachys cinerea (L.) Wight & Arn. Subsp Africana Brenan & Brumm**
73. Dicliptera melleri Rolfe
74. Dicoma anomala Sond
75. Diospyros kirkii Hiern
76. Diopyros lycioides Desf.
77. Diospyros natalensis (Harv.) Brenana
78. Diplolophium zambesianum Hiern
79. Diplorhynchus condylocarpon (Muell. Arg.) Pichon
80. Dolichos trinervatus Bak.
81. **Dombeya rotundifolia (Hochst.) Planch**.
82. Dovyalis zeyheri (Sond.) Warb
83. Duosperma crenatum (Lindau) Meyer
84. Duranta erecta L.
85. Ekerbergia benguelensis Welw. Ex. C.DC
86. Ekkerbergia capensis Sparm.
87. **Elephantorrhiza goetzei (Harms) Harms subsp. Alata Brenan & Brummitt**
88. Emilia coccinea (Sims) G. Don
89. Englerophyton magalismontanum (Sond.) T.D.Penn.
90. Eriosema englerianum Harms
91. Erythrina abyssinica Lam.
92. Erythrococca thrichogyne (Muell. Arg.) Prain
93. Euclea crispa (Thunb.) Gurke subsp. Crispa
94. Euclea divinorum Hiern
95. Euclea nalalensis A.DC.
96. Euphorbia griseola Pax var. mashonica Leach
97. Fadogia ancylantha Hiern
98. Faurea rochetiana (A. Rich.) Chiov.Ex Pichi
99. **Faurea saligna Harv.**
100. Faurea sermolli subsp. Speciosa (Welw.) Troupin
101. Ficus abutilifolia (Miq.) Miq
102. Ficus ingens (miq.) Miq
103. Ficus natalensis Hochst.
104. Ficus sur Forssk.
105. Ficus sycomorous L.
106. Ficus thonningii Blume
107. Ficus verruculosa Warb.
108. **Flacourtia indica (Burm.f.) Merr.**
109. Flemingia grahamian Wight & Arn.
110. Friesodielsia obovata (Benth.) Verdc.
111. Gardenia ternifolia Schum. & Thonn. Subsp. Jovis-tonantis (Welw.) Verdc. var. goetzei (Stapf & Hutch.) Verdc.
112. Gerbera viridifolia (DC.) Sch. Bip.
113. **Grewia flavescens Juss.**
114. Grewia monticola Sond.
115. Grewia monticola Sond.
116. Gymnosporia heterophylla (Ecklon & Zeyher) N.K.B. Robson
117. Gymnosporia senegalensis (Lam.) Excell
118. Helllichrysum nudifoliiiium (L.) Lees
119. Heteromorpha involucrate Conrath.
120. Hexalobus monopetalus (A.Rich.) Engl. & Diels var. obovatus Brenana
121. Hibiscus ovalifolius (Forsk) Vahl.
122. Hymenodictyon floribundum (Hochst. & Steud.) B.L. Robinson
123. Hex mitis (L.) Radlk
124. Indigofera antunesiana Harms
125. Indigofera arrecta Hochst ex A Rich
126. Indigpfera emarginella Dtued. Ex. A. Rich.
127. Indigoferarhynchocarpa Welw.ex Bak.
128. Indigofera setiflora Bak.
129. Indigofera swaziensis Bolus
130. Indigofeera varia E. Mey
131. Indigofera vicioides Jaub. & Spach.var. rogersii (R.E Fries) Gillett
132. Inula glomerata Oliv. & Hiern
133. Inula paniculata (Klatt) Burtt Davvy
134. **Julbernardia globiflora (Benth.) Troupin**
135. Kalanchoe lanceolata (Forsk.) Persoon
136. Kalanchoe sexangularis N.E Br.

137. Kigelia Africana (Lam) Benth
138. Kirkia acuminata Oliv.
139. **Lannea discolor (Sond.) Engl**.
140. Lannea edulis (Sond.) Engl.
141. Leptactina benguelensis (Benth. Hook.f.) Good
142. Lippia javanica (Burm.f) Spreng.
143. Macfadyena unguis-cati (L.) A. Gentry
144. Maerua angolensis DC
145. Maerua juncea Pax subsp. Juncea
146. Margaritaria discoidea (Baill.) Webster var. nitida (Pax) Radc – Sm.
147. Markhamia zansibarica (Bojer ex DC.) K. Schum.
148. Maytenus undata (Thunb.) Blakel.
149. Mikania cordata (Burm.f.) B.L. Robinson
150. Mimusops. Zeyheri Sond.
151. Monotes engleri Gilg
152. Monotes glaber Sprague
153. Mucuna coriacea Bak.subsp. irritans (Burtt Davvy) Verdc.
154. Mundulea sericea (Willd.)A. Chev.
155. Myrica serrata Lam
156. Myrothamnus flabellifolius Welw.
157. Neonotonia wightii (Arn.) Lackey
158. Ochna pulchra Hook.f.
159. Ochna schweinfurthiana F.Hoffm.
160. Ocimum americanum C.E Fries
161. Olea europaea L. subsp Africana (Miller) Green
162. Osyridicarpus schimperianus (Hochst.ex A.Rich.) A.DC
163. Osyris lanceolata Hochst. & Steud.
164. Ozoroa insignis Del.
165. Ozoroa reticulata (Bak.F.) R. & A. Fernandes
166. Pappea capensis Eckl. & Zeyh.
167. Passiflora edulis Sims
168. Pavetta schmanniana K. Schum.
169. Peltophorum africanum Sond.
170. Pentas angustifolia (A. Rich. Ex DC.) Verdc.
171. Pericopsis angolensis (Bak.) van Meeuwen
172. Phaulopsis imricata (Forssk.) Sweer subsp. Imbricata
173. Phyllanthus glaucophyllus Sond.
174. Phyllanthus pentandrus Schum. & Thonn.
175. Piliostigma thonningii (Schumach.) Milne-Redh.
176. Pittosporum viridiflorum Sims var. commutatum (Putt) Moeser
177. Plectranthus gracillimus (T.C.E.Fries) Hutch & Dandy
178. Pleiotaxis eximia O. Hoffm. Subsp. Eximia
179. Pleurosssssstylia Africana Loes.
180. Polygonum salicifolium Willd.
181. Pouzolzia mixta Solms
182. Protea angolensis Welw.
183. Protea gaguedi Gmel.
184. Protea welwitschii Engl. Subsp welwitschii
185. Pseudarthria hookeri Wight & Arn
186. Pseudolachnostylis maprouneifolia Pax
187. Psorospermum febrifugum Spach
188. Pterocarpus angolensis DC.
189. Pterocarpus rotundifolius (Sonder) Druce
190. Rhamnus prinoides L'Herit.
191. Rhoicissus revoilii Plach.
192. Rhoicissus tridentate (L.f.) Wild & Drumm.
193. Rhus lancea L.f.
194. Rhus leptodictya Diels
195. Rhus longipes Engl. Var. Londipes
196. Rhus tenuinervis Engl. Var. longipes
197. Rhynchosia insignis (O. Hoffm.) R. E Fries
198. Ryhnchosia resinosa (A. Rich.) Bak.
199. Rumex rhodesius Rech. f.
200. Schistostephium artemisiifolium Bak.
201. Securidaca longipedunculata Fres.
202. Senna septemtrionalis (Viv.) Irwin & Barneby
203. Senna singueana (Del.) Lock
204. Sesbania macrantha Welw. Ex Phill. & Hutch
205. Solanecio (Sch. Bip.) Walp. Angulatus (Vahl) Jeffrey
206. Solanum incanum L. susp. Delagoense

207. Spermacoce senensis (Klotzsch) Hiern
208. Sphenostylis marginata E. Mey.subsop. erecta (Baker f.) Verdc.
209. Steganotaenia araliacea Hochst
210. Sterculia quinqueloba (Garcke) K. Schum.
211. Stereospermum kunthianum Cham.
212. Strychnos innocua Delil.
213. Strychnos madagascariensis Poir.
214. Strychnos potatorum L.F.
215. Strychnos spinosa Lam.
216. Syzygium cordatum Hochst. Ex Sond
217. Syzygium guineense (Willd.) DC.
218. Tagetes minuta L.
219. Tapipyllum velutinum (Hiern) Robyns
220. Tarenna neulophylla (S. Moore) Brenan
221. Teclea rogersii Mendonca
222. Tephrosia acaciaefolia Bak.
223. Tephrosia decora Bak.
224. Tephrosia heckamanniana Harms
225. Tephrosia lepida Bak.f
226. Tephrosia micantha Gillett
227. Terminalia sericea Burch ex Dc
228. Terminalia stenostachya Engl. & Diels
229. Tetradenia riparia (Hochst.) Codd
230. Thesium goetzeanum Engl.
231. Thunbergia crispa Burkill
232. Thunbergia lancifolia T. Anders.
233. Tinnea rhodesiana S. Moore
234. Tithonia rotundifolia (Mill.) Blake
235. Tricalysia niam-niamensis Hiern
236. Triumfetta rhomboidea Jacq.
237. Turraea nilotica Kotschy & Peyr. Var. nilotica
238. **Uapaca kirkiana Muell. Arg**.
239. Uapaca nitida Muell.Arg
240. Vangueria infausta Burchell subsp. Infausta
241. Vangueria randii S. More
242. Vangueriopsis lanciflora (Hiern) Robyns
243. Vernonia adoensis Sch. Bip. ex Walp. Var. kotschyana (Schip Bip. Ex Walp.) Pope
244. Vernonia amygdalina Deli.
245. Vernonia exertiflora Bak
246. Vernonia glaberima Welw. O. Hoffin
247. Vernonia karaguensis Oliv. & Hiern
248. Vernonia melleri Oliv. & Hiern
249. Vitex payos (Lour.) Merr
250. Withania somnifera (L) Dunal
251. Ximenia Americana L var. Americana
252. Ximenia caffra Sond. Var. caffra
253. Zanha Africana (Radlk.) Exell
254. Ziziphus mucronata Wild.

APPENDIX 2

ANALYSIS OF VARIANCE

———— 02/05/05 14:55:14 ————————————————————

General Linear Model: Spp richness versus Aspect, Zone (slope position)

```
Factor     Type Levels Values
Aspect    fixed      3 1 2 3
Zone      fixed      3 1 2 3

Analysis of Variance for Spp rich, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS       F      P
Aspect      2      1.733      1.733      0.867    0.27  0.761
Zone        2      8.133      8.133      4.067    1.29  0.287
Error      40    126.133    126.133      3.153
Total      44    136.000
```

General Linear Model: Spp diversity versus Aspect, Zone

```
Factor     Type Levels Values
Aspect    fixed      3 1 2 3
Zone      fixed      3 1 2 3

Analysis of Variance for Spp dive, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS       F      P
Aspect      2    0.27000    0.27000    0.13500    2.49  0.096
Zone        2    0.48994    0.48994    0.24497    4.51  0.017
Error      40    2.17089    2.17089    0.05427
Total      44    2.93083
```

General Linear Model: pH versus Aspect, Zone

```
Factor     Type Levels Values
Aspect    fixed      3 1 2 3
Zone      fixed      3 1 2 3

Analysis of Variance for pH, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS       F      P
Aspect      2     0.4751     0.4751     0.2376    1.08  0.348
Zone        2     0.9524     0.9524     0.4762    2.17  0.127
Error      40     8.7649     8.7649     0.2191
Total      44    10.1924
```

General Linear Model: K versus Aspect, Zone

```
Factor     Type Levels Values
Aspect    fixed      3 1 2 3
Zone      fixed      3 1 2 3

Analysis of Variance for K, using Adjusted SS for Tests
```

```
Source     DF     Seq SS     Adj SS     Adj MS       F      P
Aspect      2    0.34949    0.34949    0.17475   12.05  0.000
Zone        2    0.39601    0.39601    0.19801   13.65  0.000
Error      40    0.58009    0.58009    0.01450
Total      44    1.32560
```

General Linear Model: P versus Aspect, Zone

```
Factor     Type Levels Values
Aspect    fixed      3 1 2 3
Zone      fixed      3 1 2 3

Analysis of Variance for P, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS       F      P
Aspect      2    2509.64    2509.64    1254.82   16.51  0.000
Zone        2     325.91     325.91     162.96    2.14  0.130
Error      40    3039.56    3039.56      75.99
Total      44    5875.11
```

General Linear Model: N versus Aspect, Zone

```
Factor     Type Levels Values
Aspect    fixed      3 1 2 3
Zone      fixed      3 1 2 3

Analysis of Variance for N, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS       F      P
Aspect      2     20.844     20.844     10.422    2.06  0.141
Zone        2     49.911     49.911     24.956    4.94  0.012
Error      40    202.222    202.222      5.056
Total      44    272.978
```

General Linear Model: Clay versus Aspect, Zone

```
Factor     Type Levels Values
Aspect    fixed      3 1 2 3
Zone      fixed      3 1 2 3

Analysis of Variance for Clay, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS       F      P
Aspect      2     19.511     19.511      9.756    3.95  0.027
Zone        2      2.311      2.311      1.156    0.47  0.630
Error      40     98.756     98.756      2.469
Total      44    120.578
```

General Linear Model: Silt versus Aspect, Zone

```
Factor     Type Levels Values
Aspect    fixed      3 1 2 3
```

```
Zone      fixed      3 1 2 3

Analysis of Variance for Silt, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS       F      P
Aspect      2     72.133     72.133     36.067   20.34  0.000
Zone        2     19.733     19.733      9.867    5.56  0.007
Error      40     70.933     70.933      1.773
Total      44    162.800
```

General Linear Model: Sand versus Aspect, Zone

```
Factor     Type Levels Values
Aspect    fixed      3 1 2 3
Zone      fixed      3 1 2 3

Analysis of Variance for Sand, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS       F      P
Aspect      2     24.578     24.578     12.289    1.80  0.179
Zone        2     24.711     24.711     12.356    1.81  0.177
Error      40    273.689    273.689      6.842
Total      44    322.978
```

General Linear Model: Moisture versus Aspect, Zone

```
Factor     Type Levels Values
Aspect    fixed      3 1 2 3
Zone      fixed      3 1 2 3

Analysis of Variance for Moisture, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS       F      P
Aspect      2     595.12     595.12     297.56   61.18  0.000
Zone        2      76.19      76.19      38.10    7.83  0.001
Error      40     194.54     194.54       4.86
Total      44     865.85
```

General Linear Model Basal area Versus Aspect and Zone

```
Factor     Type Levels Values
Aspect    fixed      3 1 2 3
Zone      fixed      3 1 2 3

Analysis of Variance for BA, using Adjusted SS for Tests

Source     DF     Seq SS     Adj SS     Adj MS       F      P
Aspect      2    0.09495    0.09495    0.04748    1.08  0.351
Zone        2    0.42988    0.42988    0.21494    4.87  0.013
Error      40    1.76456    1.76456    0.04411
```

```
Total       44    2.28939
```

APPENDIX 3.

CANONICAL CORRESPONDENCE ANALYSIS AND PERMUTATION TESTS

```
1

 *** Unrestricted permutation ***


 Seeds:  23239   945



 **** Summary of Monte Carlo test ****

 Test of significance of first canonical axis: eigenvalue =     .701
                                     F-ratio    =    7.460
                                     P-value    =     .0050

 Test of significance of all canonical axes  : Trace      =    1.800
                                     F-ratio    =    2.241
                                     P-value    =     .0050

 (  199 permutations under reduced model)
No  sample-weights specified
 No downweighting of rare species

 No. of active  samples:     45
 No. of passive samples:      0
 No. of active  species:     35

 Total inertia in species data=
 Sum of all eigenvalues of CA =    3.52166


 ****** Check on influence in covariable/environment data ******
 The following sample(s) have extreme values
 Sample Environmental        Covariable  + Environment space
        variable Influence   influence     influence

     2     1      6.0x
    12     5       5.5x
    13     4     23.3x
    13     9       5.4x
    17    12       5.1x
    26    13       6.1x
    33                          3.5x
    33     3      11.2x
    33    12      10.3x
    33    13       8.4x
    41    11      12.2x
    42     3       7.9x
 ****** End of check ******


 **** Start of forward selection of variables ****
```

```
*** Unrestricted permutation ***


Seeds:  23239   945

   N     Name Extra fit

  12 WdCuttin       .05
  13 Slope         .12
   1 pH            .18
   7 Sand          .20
   4 N             .21
   5 Clay          .21
  14 Aspect        .25
   6 Silt          .28
   3 P             .30
  11 Moisture      .32
   8 Fire          .37
   2 K             .41
   9 Rock cov      .57
  10 Soil dep      .62


 P-value  .0040 (variable  10; F-ratio=  9.20; number of permutations=   250)

P-value  .0040 (variable   6; F-ratio=  3.56; number of permutations=   250)

P-value  .0040 (variable   1; F-ratio=  2.80; number of permutations=   250)

P-value  .0518 (variable   3; F-ratio=  1.91; number of permutations=   250)

 P-value  .0319 (variable   2; F-ratio=  1.88; number of permutations=   250)

 P-value  .1116 (variable   4; F-ratio=  1.63; number of permutations=   250)

 P-value  .0797 (variable   9; F-ratio=  1.52; number of permutations=   250)

 P-value  .2072 (variable  11; F-ratio=  1.35; number of permutations=   250)

 P-value  .2191 (variable   8; F-ratio=  1.25; number of permutations=   250)

 P-value  .3825 (variable  14; F-ratio=  1.11; number of permutations=   250)

 P-value  .7211 (variable  13; F-ratio=   .78; number of permutations=   250)

 P-value  .8566 (variable   7; F-ratio=   .60; number of permutations=   250)

 P-value  .8486 (variable  12; F-ratio=   .56; number of permutations=   250)




*** End of selection ***
```

```
 N      name        (weighted) mean     stand. dev.        inflation factor

 1      SPEC AX1               .0000               .8808
 2      SPEC AX2               .0000               .7662
 3      SPEC AX3               .0000               .6157
 4      SPEC AX4               .0000               .4135
 5      ENVI AX1               .0000               .8375
 6      ENVI AX2               .0000               .5806
 7      ENVI AX3               .0000               .4849
 8      ENVI AX4               .0000               .3542
 1      pH             5.9609            .4430              1.7157
 2      K              .4992             .1723              3.2653
 3      P              14.4088           13.6677            3.0948
 4      N              7.3470            3.0758             2.7493
 5      Clay           3.3113            1.6252             111.6331
 6      Silt           6.3197            1.8507             146.6303
 7      Sand           90.3608           2.6764             308.1274
 8      Fire           .5113             .4999              3.0887
 9      Rock cov       37.2852           37.4359            8.7879
 10     Soil dep       43.5656           27.5956            7.6513
 11     Moisture       6.6974            4.5178             4.9322
 12     WdCuttin       105.8803          174.8519           1.7846
 13     Slope          21.1544           16.1971            1.7947
 14     Aspect         150.9599          143.7517           6.5676




**** Summary ****

Axes                                  1         2        3        4     Total inertia

Eigenvalues:                        .701      .337     .235     .125        3.522
Species-environment correlations:   .951      .758     .787     .857
Cumulative percentage variance of:
     species data          :         19.9      29.5     36.2     39.7
  of species-environment relation:   39.0      57.7     70.7     77.7

Sum of all unconstrained eigenvalues                                    3.522
Sum of all canonical    eigenvalues                                     1.800

[Fri May 13 18:50:48 2005] CANOCO call succeeded
```

Appendix 4

CHI-TESTS ON SIZE CLASS DISTRIBUTIONS IN MAZOWE BOTANICAL RESERVE

Chi-Square Test: NE, N, NW (BA Size Classes)

```
Expected counts are printed below observed counts

           NE        N       NW    Total
    1     284      213      214      711
       272.89   216.81   221.30

    2      68       59       57      184
        70.62    56.11    57.27

    3       6       16       19       41
        15.74    12.50    12.76

    4       7        2        6       15
         5.76     4.57     4.67

Total     365      290      296      951

Chi-Sq =  0.453 +  0.067 +  0.241 +
          0.097 +  0.149 +  0.001 +
          6.024 +  0.978 +  3.050 +
          0.268 +  1.449 +  0.380 = 13.157
DF = 6, P-Value = 0.041
2 cells with expected counts less than 5.0
```

Chi-Square Test: NEB, NEM, NET (BA Size classes)

```
Expected counts are printed below observed counts

          NEB      NEM      NET    Total
    1     120       98       75      293
       106.26    98.45    88.29

    2      10       27       32       69
        25.02    23.18    20.79

    3       3        1        2        6
         2.18     2.02     1.81

    4       3        0        4        7
         2.54     2.35     2.11

Total     136      126      113      375

Chi-Sq =  1.776 +  0.002 +  2.001 +
          9.020 +  0.628 +  6.042 +
          0.312 +  0.512 +  0.020 +
          0.084 +  2.352 +  1.695 = 24.444
```

```
DF = 6, P-Value = 0.000
6 cells with expected counts less than 5.0
```

Chi-Square Test: NB, NM, NT (N-north. B-bottom slope, M- middle slope ,T- top slope)

```
Expected counts are printed below observed counts

            NB       NM       NT    Total
    1       89       63       58      210
         77.29    65.63    67.08

    2       14       23       22       59
         21.72    18.44    18.85

    3        2        3       11       16
          5.89     5.00     5.11

    4        1        1        1        3
          1.10     0.94     0.96

Total      106       90       92      288

Chi-Sq =  1.774 +  0.105 +  1.230 +
          2.741 +  1.129 +  0.527 +
          2.568 +  0.800 +  6.785 +
          0.010 +  0.004 +  0.002 = 17.675
DF = 6
* WARNING * 2 cells with expected counts less than 1.0
          * Chi-Square approximation probably invalid
3 cells with expected counts less than 5.0
```

Chi-Square Test: NWB, NWM, NWT

```
Expected counts are printed below observed counts

           NWB      NWM      NWT    Total
    1       73       81       50      204
         69.90    73.47    60.63

    2       19       16       23       58
         19.87    20.89    17.24

    3        3        6        9       18
          6.17     6.48     5.35

    4        3        0        3        6
          2.06     2.16     1.78

Total       98      103       85      286

Chi-Sq =  0.137 +  0.772 +  1.864 +
          0.038 +  1.144 +  1.926 +
          1.627 +  0.036 +  2.491 +
          0.433 +  2.161 +  0.830 = 13.460
DF = 6, P-Value = 0.036
3 cells with expected counts less than 5.0
```